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TESTS OF JET ENGINES,(U)

JAN 78 V M DOROFEYEV, V Y LEVIN

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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

TESTS OF JET ENGINES

by

V. M. Dorofeyev, V. Ya. Levin

FOREIGN TECHNOLOGY DIVISION

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By: V. M. Dorofeyev, V. Ya. Levin

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PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

TESTS OF JET ENGINES.

V. M. Dorofeyev, V. Ya. Levin.

Page 1.

Authorized

by Ministry of Higher and secondary special education of the CRSFSR as textbook for Aviation VUZ [Institute of Higher Education] and departments.

Page 2.

In the book are examined the different types of the tests of jet engines. It is described technician and the methods of processing measurements, measuring instruments and devices, the equipment of laboratories and experimental stations.

The book is textbook on analogous/similar with its name course and is intended for the students of aviation VTUZ [Higher technical educational institution]; at the same time it will be useful for the engineers of industry.

Page 3.

PREFACE.

In the different countries with to the creation of jet engines (VRD [jet engine]) they will approach into middle of the thirtieth years. Very considerable attention to these engines allotted in the period of the Second World War, which will ensure to its end the issue of the first series jets. Wide series production VRD and their operation will be begun virtually after completion of war, moreover widest use will receive at present turbojet and turboprop engines.

The creation of new engines will require the perfection/improvement of the methods of their tests. In the first years of the development of jet/reactive aviation of the technician of tests VRD, it stands at low level - testing units and metering

equipment are very inadequate. Afterward 1945 in a number of the countries were created the special experimental stations and the laboratories, equipped with the modern metering equipment and the necessary equipment.

Procedure the technician of engine tests, being developed on the base of the achievements of aviation equipment, it will be added at present into independent engineering discipline.

Unfortunately, text literature for VTUZ on this discipline until this time barely is published. The proposed book is the first attempt in this region. The authors strive in the small by volume book to sufficient widely introduce the reader to theory and tests technique VRD; therefore many questions were presented with possible brevity.

For the first time in academic literature on testing of aircraft engines, are reflected experimental and flight tests. Primary attention in the book is devoted to the methods of the tests of the most widely used types VRD - turbojet and turboprop engines.

Observations of work of those beginning engineer-tester will lead the authors to the conclusion/derivation that with the presentation of the questions of measurements (taking into account the limitedness of the volume of textbook) it is better to illuminate

the operating principles and devices of instruments, than the procedure of their application/use.

In the book barely examined the questions of the calculation of testing units and their cell/elements.

Page 4.

To the readers, who specialize in the region of the tests of aircraft engines, necessary to turn to additional sources (see bibliography at the end of book).

On request and edited by the authors chapter VI will write eng. S. N. Eremin, but chapter VII eng. V. S. Kondrusev.

The authors are grateful to docents G. M. Gorbunov, to L. B. Yevangulov, Yu. K. Zastel, Cand. of tech. sciences A. A. Lakshtovskiy and eng. Z. L. Kropp for a series of valuable observations and councils, made about the prospectus of the manuscript and during its review. The authors are grateful also to eng. V. N. Pikulyu and colleagues of the department of TAD Kuibyshevskiy of aviation institute for shaping of the manuscript. Extensive work on the editing of the manuscript was conducted by L. S. Skubachevskiy, to whom the authors express special appreciation.

All observations and wishes about content and shaping of the book it is requested to direct to: Moscow, I-51, Petrovka, 24, Oborongiz.

Page 5.

Chapter I.

TYPES OF THE TESTS OF AIR-JET ENGINES.

Engine tests, conducted at plants, in experimental design bureaus and scientific research institutes, it is possible to classify depending on the place of their execution and the expressed goal.

On the place of test work, are divided into the ground-based and flight.

Ground tests they are called all the tests, conducted on the earth/ground, including at the settings up, which imitate high-altitude and high-speed/velocity flight conditions.

Flight tests they are called engine test in flight on special aircraft - flying laboratories, and also on experimental or production aircraft and on unmanned vehicles.

Depending on the purpose of the test, are divided into the scientific research, experimental and series (see schematic).

Let us examine the special feature/peculiarities of each type of tests.

1. Scientific research tests.

The purposes of the scientific research tests can be different, but their primary task is study and analysis the occurring in engine or its aggregate/units of the phenomena and processes. Scientific research tests usually are carried out for research on thermodynamic and gas-dynamic processes in engine, work of separate units, fuel/propellant and processes of its burning, analysis of the characteristics of engine, strength of its parts, etc.

During the development of fundamentally new constructions, performing scientific research work is complicated by the insufficient knowledge of some occurring in engines physical phenomena and often by the absence of the necessary metering equipment.

Thermodynamic and gas-dynamic research of input devices, compressors, combustion chambers, turbines and engine nozzles as taking their characteristics, can be conducted under actual conditions in special laboratories with the complex and bulky equipment, which requires considerable energy powers.

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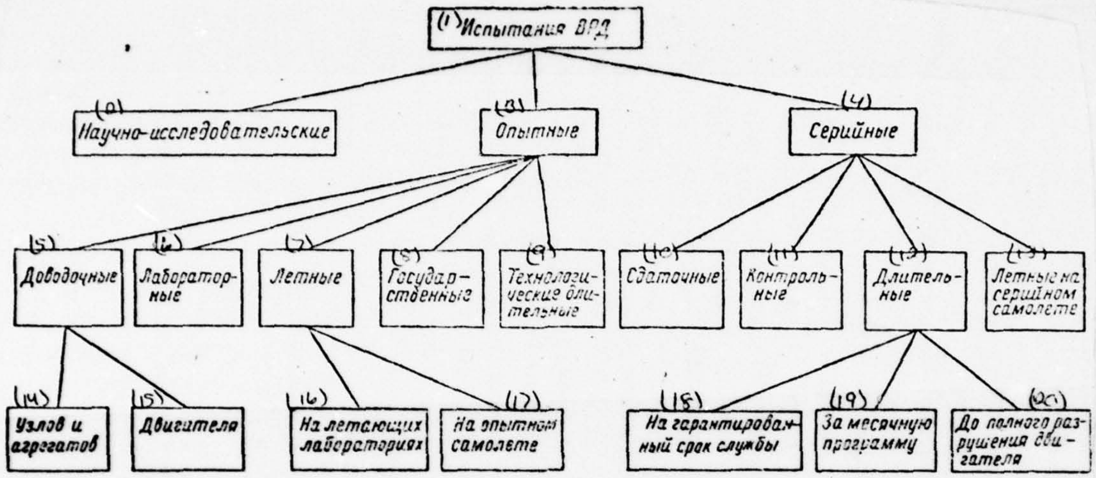

Classification of tests.

Key: (1). Tests VRD. (2). Scientific research. (3). Experimental. (4). Series. (5). Finishing. (6). Laboratory. (7). Flight. (8). State. (9). Technological prolonged. (10). Delivery. (11). Controls. (12). Prolonged. (13). Flight on production aircraft. (14). Units and aggregate/units. (15). Engine. (16). On flying laboratories. (17). On experimental aircraft. (18). For the guaranteed service life. (19). For monthly program. (20). Before the complete destruction of engine.

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Theory of similitude makes it possible to conduct the approximate tests of engine components on their models. For model test, are required the settings up of considerably smaller powers, which gives essential economic advantages.

The strength of engines, their units and parts usually he is studied in special laboratories.

The results of scientific research tests make it possible to understand the character in engine of operating conditions taking place, to establish/install the reasons for the appearing in it phenomena, to refine and to supplement the existing theoretical positions and the calculation methods. Sometimes the sums of tests can serve as basis for the creation of the new methods of calculation and theoretical generalizations.

Scientific research tests are carried out usually in scientific research institutions, schools of higher education and sometimes in experimental design bureaus.

2. Experimental tests.

The basic goal of experimental tests is the adjustment of operating conditions and constructions of engine. Experimental tests utilize results of scientific research tests. The absence of precise theory of some phenomena, which occur in engine, does not halt the experimental work, although slows down their course. The experimental tests of engine consist of finishing, laboratory, flight, state and technological endurance tests. Finishing tests are conducted according to two directions: in plant laboratories are developed the aggregate/units and the separate units of engine, at experimental experimental stations - full-scale engines. Such tests most frequently are carried out under conditions of the environment.

In the task of finishing tests, enter;

1) the adjustment of operating conditions of engine;

2) the adjustment of the construction of separate units and aggregate/units;

3) testing the correctness of the selection of materials and technology of the manufacture of parts;

4) the determination of the engine life and the research of measures for his increase;

5) the finishing of the parameters of engine in different mode/conditions up to the values, indicated in the requirements for client.

Independent of finishing tests of engines, conducted on experimental plants, are conducted their laboratory tests in scientific research institutes - the high-altitude laboratories, equipped with heatandpressure simulation chambers and the wind tunnels, which make it possible to create on the earth/ground the necessary high-altitude and high-speed/velocity flight conditions and to remove/take the corresponding to these conditions engine characteristics.

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Sometimes in such laboratories are carried out special tests according to the programs, which consider specified operating conditions of engine (low or high temperature, the condition of deserts, rains etc.).

After the successful conducting of finishing and laboratory tests, they begin the experimental flight tests. Experimental flight tests, as a rule, are carried out first on special aircraft - flying laboratories. Tests on flying laboratories are carried out sometimes before the completion of the finishing of engine. Flight safety in this case is guaranteed by the presence on the flying laboratory of series power plants and by the decrease in the service life of the tested engine. Flying laboratories they usually limit possibility of tests of engines on velocity and flight altitude.

After the careful functional check of engine on the flying laboratory of testing, they are continued on the experimental aircraft, designed for this engine. During tests is determined the reliability of the operation of power plant as a whole and conformity to its technical specifications.

It is natural that in the period of conducting laboratory and flight tests can be reveal/detected the new engine defects. These defects must be removed, after which engines again undergo the tests.

After the completion of the finishing tests of engine, they present to state tests. Official tests are carried out under

terrestrial conditions at the station of experimental plant for specific routine. The mode/conditions of tests, their duration on time and the order of their alternation are selected so that the engine operation during tests would possibly nearer correspond to the future conditions of its operation. So, for example, turbojet and turboprop engines they test in the nominal, forced (takeoff and combat) and cruise settings.

Nominal rating corresponds to design conditions of engine. Under these conditions of engine, it must reliably work the significant part of its service life. Tests under these conditions are conducted by periods in continuous operation of engine during 30 min.

The forced mode/conditions (takeoff and combat) are reached by an increase in the number of revolutions of shaft of turbine, by an increase of the temperature of gases after turbine or afterburner ignition. Such mode/conditions can be also obtained by the combined means of effect on operating conditions of engine. The forced mode/conditions are applied incidentally for the takeoff of the overloaded aircraft or for a short-term increase in the flight speed and rate of climb. Engine it must reliably work in these mode/conditions during 5-10 min with the subsequent transfer/transition to more light duty.

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The time of continuous operation of engine on nominal and forced ratings can change in certain range depending on the designation/purpose of the flight vehicle on which it is utilized engine.

Cruise setting - this is the mode/conditions at which the number of revolutions of the shaft of turbine and the temperature of gases after it are lower than on nominal. For TVD [turboprop engine] cruise setting can be establish/installed by the appropriate change in blade angle of attack of propeller with the preservation/retention/maintaining of the constant engine speed. The duration of continuous operation under these conditions is not limited.

The programs official tests of just one type different engines can differ from each other under the conditions and in duration and are determined by the ultimate purpose of engine. The conclusion of state board about successful test work serves as base/root for the direction of engine into series production.

Work on the further improvement of engine after its transfer to series production does not cease. Developmental bureaus (OKB

[Experimental Design Bureau]), which exist with the leading series plants, attempt to improve performance data the produced by plant engines and to raise their resource/lifetime. In connection with this on the experimental stations of series plants, periodically are carried out the endurance tests of the engines, into construction or under operating conditions of which are introduced any changes. These tests they are called technological endurance tests and they are carried out according to the specific routine, developed/processed by OKB. Successful test work gives the right to plant to introduce the necessary changes and to begin the issue of new motor line.

3. Production type tests.

Production type tests are carried out on the experimental stations of manufacturing plants under conditions of the environment. Are distinguished the following types of production type tests: delivery, controls, prolonged and flight.

Acceptance tests passes each produced by plant engine. tests carry out for quality control and the breakings in of parts, correctness of assembly and adjustment of the operation under the conditions for the target/purpose of the provision for conformity of

its basic specifications conditions.

If in the process of acceptance tests is reveal/detected the nenconformity of engine data that which was assigned or the defect which can lead to emergency, then tests cease. After the elimination of engine defects, again undergo acceptance tests.

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Each engine after acceptance tests they dismantle for the inspection of all parts and their flaw detection and direct then to monitoring tests for the functional check of engine on all mode/conditions, stipulated under technical specifications. With the satisfactory results of monitoring test engine it is accepted as client and leaves to dispatch. During monitoring test must not be of any malfunctions. During flaw detection, the monitoring test is nullified.

Prolonged production type tests are divided into:

1) test for guaranteed engine life to the first sorting/partition;

2) engine test for the monthly program (duration of tests

-50-100 of hours);

3) of testing to the complete destruction of engine.

Prolonged production type tests are carried out through the standard programs official tests, with the exception of taking some special characteristics.

The periodicity of tests depends on their designation/purpose. Tests for guaranteed by plant service life carry out one time into quarter, and for monthly program - one time in month. The periods of conducting endurance tests can be changed depending on the program of the issue of engines.

Furthermore, is possible the coincidence of tests. For example, when is carried out testing for guaranteed by plant engine life to the first sorting/partition, this testing is considered also testing of engine for the current monthly program. In this case the solution to the issue of the engines of given month is accepted on the basis of test results for guaranteed resource/lifetime. The satisfactory result of series endurance test gives right to plant to the further issue of engines during given month.

Endurance test is conducted in the stages the interruption

between which is permitted within the limits of the time, necessary for production of routine maintenance work.

Endurance tests are considered unsatisfactory, if for the time of tests or with internal inspection after tests is reveal/detected service failure of the parts, breakage or damage of which will entail the emergency of engine. In this case the shipment of engines from plant ceases up to obtaining of the positive results of the repeated endurance test which is carried out after the elimination of defects.

Endurance tests of production engines before their complete destruction make it possible: to test reliability and to determine the service life of the parts of engine and its aggregate/units; to refine repair technology; to test quality and nomenclature of repair-assembly tools and appliances; to refine tables of limits for the maximum wears of parts and clearances in articulation for repair engines; to refine the content of the group assembly of spares for the first, the second and all subsequent sorting/partitions.

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Tests to complete destruction pass all newly introduced in a series or the undergone substantial changes engines. For testing is taken the engine, passed testing for guaranteed by plant service

life. Testing carries out by the periods, equal to the service life of engine. After each period the engine passes the sorting/partition during which is carried out the flaw detection of parts. The worn parts are replaced new from the group assembly of spares. The sorting/partition of engine produces on repair technology with the instrument, produced by plant specially for a repair. Testing is considered finished, if for the operating time of engine goes out of order a considerable quantity of parts, designation and number of which is specified by technical specifications.

Vital importance has an increase in the service life of the engine, which well showed itself in operation. For the solution to this question, is take/selected the batch of the engines, which mastered the guaranteed by plant service life under operating conditions. The part of the engines from this batch heads for manufacturing plant for inspection and the flaw detection and additional bench tests.

During the determination of the duration of additional bench tests, they are accepted into consideration results of inspection and flaw detection of the dismantle/selected engines and of the carried out it is earlier by plant tests before complete destruction. In the case of obtaining the satisfactory results of additional tests, is permitted conducting the flight tests of the remaining from batch

engines on aircraft for a period of time, which corresponds to supplementary resource/lifetime.

Successful conducting of flight tests gives the right to plant to increase the service life of the produced engines. Specific tests they are sometimes called operational.

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Chapter II.

ELEMENTS OF METROLOGY.

The development of the system of measures, measuring meters, methods of measurements and processing observed data rests on the achievements of many branches of science and engineering. The contemporary methods of processing the results of measurements were created in essence in the first half of the XIX century.

Monitoring of the observance of the uniformity of measures and their correctness in the USSR is realize/accomplished by committee of standards, measures and measuring meters and by its organ/controls. Furthermore, are organ/controls of departmental supervision for the verification/check of measures and measuring meters at plants and in the research institutions which compulsorily are recorded in the

committee of standards, measures and measuring meters.

By the organ/controls of committee believe the standard measures and measuring meters, and also the instruments of production control (if in production there are no point/items of the departmental supervision).

The methods of the verification/check cf measures and measuring meters are presented in document the "time/temporary rules of 12-54 organizations and conducting the verification/check of measures and measuring meters". The enterprises, which produce measures and measuring meters, confirm the experimental models last/latter in the committee of standards, measures and measuring meters.

With the verification/check of measures and measuring meters as absolutely precise values, are accepted international standards. The state standards of measures, determined with metrological accuracy/precision, consider true values.

1. Measures, measuring meters and their errors.

Measures are bodies or the devices, which are the real

reproduction of ones of measurement or their portions. Thus, for instance, weights are the measures of mass, light rays - by the linear measures (linear measures are also meters, centimeters), etc.

The direct comparison of the measured values with measures in the majority of cases is impossible. Therefore measurements are produced with the aid of the measuring meters, which make it possible to carry out the convenient and sufficiently precise comparison of the measured values with the taken as units of measure.

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All measures and measuring meters are divided into two groups:

1) the standard measures and reference instruments,

2) working measures and working measuring meters.

The standard measures and instruments serve for reproduction and storage of taken ones of measurement, and also of their fractional or multiple parts. Sometimes standard instruments are applied for precise measurements in the experimental work. Working measures and instruments - these are still measures and instruments, with the exception of specimen.

The result of measurements, which they read on the scale of measure or instrument, he is called nominal. The value of the measured quantity, obtained with the aid of more precise standard instrument or measure, he is called real. If measurements are conducted with the aid of standard instruments, then real value is determined by more precision instruments.

The difference between the nominal and actual value of value calls an absolute error in the measure or instrument, which can be represented in the following form:

$$\Delta = \alpha_{\text{н}} - \alpha_{\text{д}}, \qquad (1)$$

where $\alpha_{\text{н}}$ - a nominal value;

$\alpha_{\text{д}}$ - actual value.

The absolute correction of measure or instrument he is called the error, undertaken with the opposite sign:

$$\delta = -\Delta = \alpha_{\text{д}} - \alpha_{\text{н}}. \qquad (2)$$

It is obvious that

$$\alpha_{\text{д}} = \alpha_{\text{н}} + \delta. \qquad (3)$$

From expression (3) it is evident that the actual value of the measured value is an algebraic sum of the nominal value of value and

correction.

For example, are two working rules with a length of 100 mm each. During comparison with the standard measure, it turned out that the effective length of the first rule was equal to 100.1 mm, and the effective length of the second rule was equal to 99.8 mm. Then an absolute error in the first rule

$$\Delta_1 = 100 - 100{,}1 = -0{,}1 \text{ mm}$$

and second

$$\Delta_2 = 100 - 99{,}8 = 0{,}2 \text{ mm}.$$

Correction for the first rule is equal to 0.1 mm, and for second minus 0.2 mm.

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Besides absolute, frequently are determined relative errors. Relative errors in o/o are calculated according to the formulas:

the real relative error

$$\Delta_A = \frac{a_H - a_A}{a_A} 100; \qquad (4)$$

the nominal relative error

$$\Delta_{н}=\frac{a_{н}-a_{д}}{a_{н}}100;. \quad (5)$$

the given relative error $\Delta_{п}=\frac{a_{н}-a_{д}}{a_{п}}100,$ (6)

where $a_{п}$ is the infinity of instrument.

Example. During engine, testing is measured the gas pressure behind turbine with the aid of two manometers. Working manometer in mechanic will show pressure 2.1 kg/cm² (nominal value). At the same time specimen manometer fixed the pressure, equal to 2.15 kg/cm², which is considered real value.

An absolute error of measurement is equal to

$$\Delta=p_{н}-p_{д}=2,10-2,15=-0,05 \text{ kg/cm}^2.$$

Correction will be

$$\delta=p_{д}-p_{н}=2,15-2,10=0,05 \text{ kg/cm}^2.$$

Relative errors in this case will be equal to

$$\Delta_{д}=\frac{-0,05}{2,15}\cdot100=-2,32\%$$

and

$$\Delta_{н}=\frac{-0,05}{2\cdot10}\cdot100=-2,38\%.$$

Usually in the practice of the measurements of value $\Delta_{Д}$ and $\Delta_{Н}$ are very close to each other and relative error can be defined both with respect to nominal and to the actual value of the measured value, without making the difference between them.

Besides the indicated absolute and relative errors, is applied another concept of the permissible error (by absolute or relative). By the permissible error is understood the maximum instrument error, stipulated by command.

The important index of the quality of instrument is the constancy of its readings, which is estimated at variation. A variation in the instrument he is called the greatest difference between the results of value one and the same measurements, manufactured under one and the same conditions.

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The important characteristic of instrument is its sensitivity, determined by the formula

$$S=\frac{\Delta n}{\Delta A}, \tag{7}$$

in which

Δn - a number of scale divisions;

ΔA - a number of ones of the measured value, which correspond Δn.

The classification of measures and measuring meters is produced on the kind of the measured value, operating principle, the method of transmission of measuring data, dimensions, accuracy/precision, the field of application, etc.

Instruments are divided using the method of obtaining the measured value into comparing, showing and those who integrate.

The comparing instruments are called such, which make it possible to compare measure and the measured value (i.e. in the assembly of the comparing instrument compulsorily it enters and measure). As an example of the comparing instrument it is possible to indicate cup weights (one cup place the measured value, to another the set of measures - the weights, which balance the measured value).

The reading instruments are called such, which make it possible to make direct reading of the value of the measured quantity. The

majority of the used instruments belongs precisely to this type. The reading instruments include dial weights, hours, manometers, dynamometers, thermometers, etc.

The integrating instruments include the summing instruments (total revolution counters, the flow meters of liquid, gases, electric power, planimeters etc.).

Using the method of recording, the instruments are divided into:

1) direct-readings instrument (manometers, dynamometers etc.);

2) recording (i.e. with the automatic recording of readings);

3) controlling (i.e. the measuring parameters of process and through the appropriate devices affecting its course);

4) of local and remote action.

Instrument accuracy is characterized by the value of the maximum given relative error or by the class of precision. For example, the instrument of class 0.5 has permissible given relative error ±0.5o/o. Depending on accuracy/precision, all instruments are divided into classes.

Measures and instruments are divided also into laboratory (for precise measurements in laboratories) and technical (for less precise measurements). During measurement by laboratory instruments, are considered the corrections to their readings, and in certain cases are carried out special experiments for determining the accuracy of measurement. During measurement by technical instruments by the accuracy of measurements they are assigned previously on the basis of specifications of instrument.

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The standard measures and instruments are divided into:

1) standards;

2) the standard measures and the instruments of the limited accuracy/precision (more frequent - simply standard measures and instruments).

Standards are measures and the instruments of the highest (metrological) accuracy/precision. The accuracy/precision of standards is retained because of their rare application/use and

storage under special conditions. The standard measures and instruments have smaller accuracy/precision and believe with the aid of working standards.

The classification of standards, of the standard measures and instruments, the methods of provision and preservation/retention/maintaining of their accuracy/precision are examined in detail in the courses of metrology.

2. Forms of measurements.

Are distinguished direct/straight and indirect measurements. When conducting of direct measurements, the unknown value is determined with the aid of measure or instrument directly. Indirect measurements are carried out when direct measurements are difficult or impossible. As an example of indirect measurement, it is possible to give the case of power measurement, when for obtaining the numerical value of this quantity it is necessary to separately measure the revolutions and the torque/moment, but power coefficient to calculate according to formula.

Direct measurements are carried out most frequently by the

following methods:

1) by direct evaluation (for example, temperature measurement mercury thermometer, the measurement of weight on weights etc.),

2) by differential method (is measured the difference between the unknown and known values),

3) by null method (action of the measured value is balanced previously by the known counteraction). By an example of the application/use of a null method can serve weighing on equal-arm weights, measurement emf of thermocouple as potentiometric method, the measurement of the reaction force of combustion chamber by bringing the arrow/pointer of suction gauge to zero so forth.

3. Errors of measurement.

During measurement always appear the errors, which can be divided into subjective and objective. Subjective errors depend on the properties of observer, on shortcomings in his sense organs and nervous system.

Let us first of all give examples of the errors of view. In Fig. 1, distance between points a and b seems considerably greater than between points b and c. It is easy to ascertain that the points are located on equal distance from each other.

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In Fig. 2, angle AOB seems greater than angle A'O'B'. In actuality they are equal.

Fig. 3, depicts the vertically arranged/located small circles. It seems that their right edges are arrange/located on curve, bent to the left. It is easy to ascertain that they lie/rest on straight line.

The widespread in observers organic defects of view and audition also affect the accuracy of measurements.

When conducting of the experimental work, is very important the speed of reaction to the obtained signal. Experiments show that the reaction (motion of finger/pin) after obtaining of the strong sound signal begins after 0.082-0.195 s., but during obtaining of the weak signal on 0.06-0.07 s., it is slower.

Given information must convince the reader of the need for

critical relation not only to the methods of measurements and instruments, but also to the properties of the competitors of measurements.

The reason for the appearance of objective errors are inaccuracy in the instruments, the limitedness of the time of measurements, the inertness of instruments and entire testing unit as a whole, ambient effect on instruments and setting up.

Are distinguished also systematic and random errors and errors.

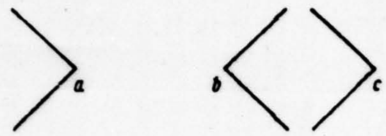
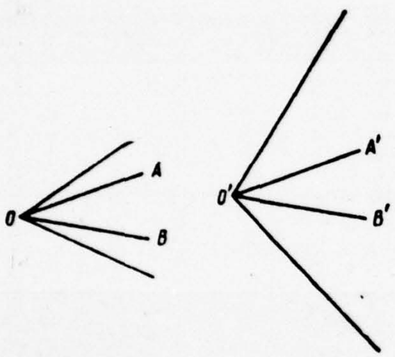


Fig. 1. Evaluation of distance between points.



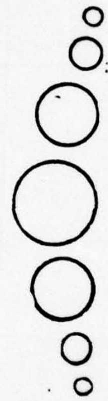


Fig 2. Fig. 3

Fig. 2. To estimate of the magnitude of angles.

Fig. 3. To evaluation of form.

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Systematic errors can be different origin and are divided on:

1) instrument/tool - appearing as a result of inaccuracies in the instruments;

2) adjusting - due to the misadjustment of the metering equipment (nonhorizontality, misalignments etc.);

3) personal - appearing due to the special feature/peculiarities of the observer (incorrect evaluation of color, slow reaction to events, shortcomings in the audition etc.);

4) of the method of measurements - for example, during the measurement of the temperature of stagnation of gas flow by thermocouple with the open joint etc.;

5) theoretical - appearing as a result of the application/use of inaccurate or erroneous formulas for processing of experimental data.

Systematic errors cannot be completely destroyed, but in the practice of experiment, always they approach their elimination or precise account.

Instrument/tool and adjusting errors are decreased by

structural/design procedures, the calibration of instruments (by comparison of readings with specimen and the introduction of the corresponding corrections into readings of service instruments), correct instrumentation, their protection from vibrations, dust, jerk/impulses. The rules of instrumentation usually are indicated in their descriptions.

Personal errors can be decreased by the selection of testers, who satisfy definite requirements. When this is impossible, it is necessary to approach the creation of the automatic and semiautomatic measuring systems whose work does not depend on the properties of tester.

Theoretical errors and errors in the method of measurements can be excluded or decreased as a result of detailed preliminary research on the theory of the phenomenon, selected system of the measurements, used instruments and other experimenters's experience.

The taken into account previously systematic errors on test result effect do not have.

The random errors are unavoidable. The reasons for their appearance for each specific case are unknown. By research on these errors is occupied theory of errors.

Errors are the exaggerated errors, which are the consequence of the inattention of observer or malfunctions in measuring systems. During processing of test results, the errors are not considered.

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4. Processing experimental data on the method of least squares.

For obtaining the most precise values of the measured quantities processing observed data is carried out through the method of least squares. The bases of this method were created by Gauss for processing of astronomical observations into 1808. Gradually the method of least squares has been used also in other fields of knowledge.

An especially large value a method of least squares has during the adjustment of a precise test installation and during gas-dynamic investigations. For processing of the results of experiment on this method necessary to have the considerable number of experimental points (on each mode/conditions one should carry out not less than 10

measurements)that restricts its application/use during the tests of full-scale engines. The bases of the method of least squares are briefly examined below.

Theorem of compound probability.

The probability of event is called the ratio of the number of cases of the appearance of an event to the number of all equally likely cases.

Thus, for instance, if of 100 tested engines of 5 engines they have nonuniform temperature field, then the probability of the appearance of engines with this defect in the following batch of engines was equal to 0.05 (if, of course, accepted no measures to the elimination of this shortcoming).

For the substantiation of the method of least squares important value has the theorem of compound probability.

Theorem. The probability of the joint appearance of two independent events is equal to the product these of probabilities the independent of each other events.

Let the probability of the first event

$$p_1 = \frac{m_1}{n_1}$$

and the second

$$p_2 = \frac{m_2}{n_2}.$$

The total number of equally likely cases is equal $n_1 \cdot n_2$, since to each event of the first group can correspond any of the events of the second group.

The number of favorable cases for the same reason is equal $m_1 \cdot m_2$. Since the joint appearance of two independent events is also event, then

$$p = \frac{m_1 \cdot m_2}{n_1 \cdot n_2} = p_1 \cdot p_2. \qquad (8)$$

which was required to prove.

Law of the distribution of the random errors.

As the basis of the derivation of the formula, which expresses

the law of the distribution of the random errors (law of Gauss), is placed the theorem of compound probability and the following axioms:

1. Equal in absolute value, but different in sign errors appear equally frequently.

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2. Frequency of appearance of low errors is more than frequency of appearance of large. Very large errors are not encountered.

The taken axioms rest on the immense experiment of studies in the different fields of science. After passing to the conclusion/derivation of the law of Gauss, let us suppose that it is carried out by N of value one and the same measurements. In this case, are noted the greatest errors +a and -a. Let us apply values +a and -a to the horizontal axis of errors x. Cut between points -a and +a (Fig. 4) on the axis of errors let us break down to large number n of parts. From the total number of measurements N, some number of measurements dN will have errors, which fall on cut dx, which is located at a distance x from the origin of coordinates 0. Distance x in this case characterizes magnitude of error. It is possible to assume that

$$dN = Nf(x)dx, \qquad (9)$$

where f(x) - the unknown function, which expresses the distribution of errors;

N - the known number of measurements.

The probability of the appearance of error x on cut dx will be

$$dp=\frac{dN}{N}=f(x)\,dx.$$

From the first axiom, accepted by us in the beginning of conclusion/derivation, it follows that

$$f(x)=\varphi(x^2).$$

since symmetrical relative to the origin of the coordinates of 0 error they are encountered equally frequently. Then after substitution we obtain

$$dp=\varphi(x^2)\,dx. \tag{10}$$

For determining the form of the function $\phi(x^2)$ let us examine the problem, connected with firing into target. Let the rifleman/gunner attempt to hit the center of target, which coincides with the origin of coordinates 0 (Fig. 5).

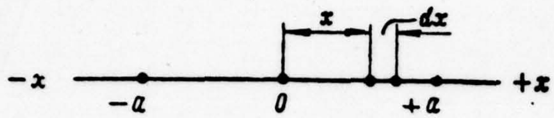

Fig. 4. To derivation of formula of Gauss.

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Experiment shows that the holes in target in a good rifleman/gunner densely are furnished near the center of target and than further from it, by those of hole they are encountered more rarely. Probability that from N of shots dN falls into the shaded rectangle m, will be

$$dp=\frac{dN}{N}=\varphi(x^2)\,dx\,\varphi(y^2)\,dy. \qquad (11)$$

Let us now pass to that which was turned the axle/axes of coordinates ξ and η moreover axle/axis ξ is passed through the middle of rectangle m, as shown in Fig. 6.

It is obvious that

$$\xi^2=x^2+y^2$$

and the probability

$$dp=\varphi(0)\,d\eta\,\varphi(\xi^2)\,d\xi, \qquad (12)$$

but

$$\varphi(\xi^2)=\varphi(x^2+y^2),$$

then

$$dp=\varphi(0)\cdot d\eta\varphi(x^2+y^2)d\xi. \qquad (13)$$

After accepting $d\xi d\eta = dx dy$, we will obtain

$$dp=\varphi(0)\varphi(x^2+y^2)dx\,dy. \qquad (14)$$

After connecting further expressions (11) and (14), let us find

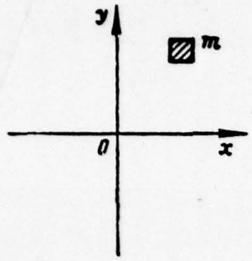
$$\varphi(0)\varphi(x^2+y^2)=\varphi(x^2)\varphi(y^2). \qquad (15)$$

Thus, we will obtain the functional equation, making it possible to determine the form of the function $\phi(x^2)$. Let us manufacture substitution $x^2 = u$, $y^2 = v$, $\phi(0) = c$; in this case equation (15) will take the form

$$c\varphi(u+v)=\varphi(u)\varphi(v). \qquad (16)$$

From preceding/previous it is obvious that u and v are independent of each other and can acquire any values. Let $v = k$, where k is a constant value. Then equation (16) will take the form

$$c\varphi(u+k)=\varphi(u)\varphi(k). \qquad (17)$$



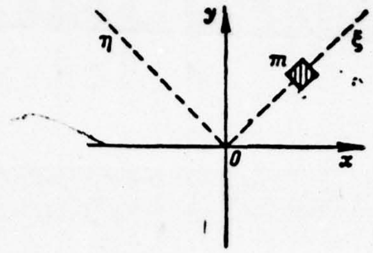


Fig. 5. Target.

Fig. 6. Target with turned coordinates.

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It differentiated equation (17) for u, we will obtain

$$c\varphi'(u+k)=\varphi(k)\varphi'(u). \qquad (18)$$

It is divided equation (18) into (17)

$$\frac{\varphi'(u+k)}{\varphi(u+k)}=\frac{\varphi'(u)}{\varphi(u)} \qquad (19)$$

and let us demonstrate that these fractions are equal to some constant for the present instance number.

After considering that

$$\omega(u)=\frac{\varphi'(u)}{\varphi(u)}$$

and

$$\omega(u+k)=\frac{\varphi'(u+k)}{\varphi(u+k)},$$

we will obtain

$$\omega(u)=\omega(u+k). \tag{20}$$

Equation (20) is correct at any values of u and k, including with u = 0.

Function $\omega(k)$ retains its value at any values of k, i.e., $\omega(k)$ = const. Consequently, function $\omega(u)$ = const independent of u. Hence follows

$$\frac{\varphi'(u)}{\varphi(u)}=b. \tag{21}$$

After the integration

$$\ln\varphi(u)=bu+\ln C,$$

whence

$$\varphi(u)=Ce^{bu} \tag{22}$$

or

$$\varphi(x^2)=Ce^{bx^2}. \tag{23}$$

After taking into consideration the second axiom according to which the function $\phi(x^2)$ must be decreased with increase in x, it is

possible to assign by constant $b = -(1/h^2)$ and to obtain

$$\varphi(x^2)=Ce^{-\frac{x^2}{h^2}}. \tag{24}$$

It is obvious that all errors carried out N of tests are packed on the axis of errors x in the range of $-\infty$ to $+\infty$, i.e.,

$$dN=N\varphi(x^2)\,dx$$

and

$$N=N\int_{-\infty}^{+\infty}\varphi(x^2)\,dx,$$

whence

$$\int_{-\infty}^{+\infty}\varphi(x^2)\,dx=1. \tag{25}$$

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Integral

$$\int_{-\infty}^{+\infty}e^{-\frac{x^2}{h^2}}dx=h\sqrt{\pi}, \tag{26}$$

consequently,

$$C=\frac{1}{h\sqrt{\pi}}.$$

Thus,

$$f(x)=\varphi(x^2)=\frac{1}{h\sqrt{\pi}}e^{-\frac{x^2}{h^2}}. \tag{27}$$

The formula, which expresses the law of Gauss, will take the

form

$$dp = \frac{1}{h\sqrt{\pi}} e^{-\frac{x^2}{h^2}} dx. \qquad (28)$$

The unknown thus far value h can be found as follows. The number of errors on cut dx, arrange/located at a distance x from the origin of the coordinates of the axle/axis of errors, is equal

$$dN = Nf(x)\,dx = \frac{N}{h\sqrt{\pi}} e^{-\frac{x^2}{h^2}} dx. \qquad (29)$$

With the summation of the squares of errors into sum, will enter the expression

$$x^2 dN = N \frac{1}{h\sqrt{\pi}} x^2 e^{-\frac{x^2}{h^2}} dx.$$

The theoretical value of the sum of the squares of errors can be determined by the integration of the preceding/previous expression within limits from-∞ to +∞:

$$S_{\text{т}} = \frac{N}{h\sqrt{\pi}} \int_{-\infty}^{+\infty} x^2 e^{-\frac{x^2}{h^2}} dx = N \frac{h^2}{2}, \qquad (30)$$

whence it follows

$$\frac{h^2}{2} = \frac{S_{\text{т}}}{N}. \qquad (31)$$

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After designating the error by

$$\varepsilon_i = l_i - L,$$

where l_i - the measured value of quantity;

L - the true value of quantity.

we will obtain

$$S_\tau = \varepsilon_1^2 + \varepsilon_2^2 + \ldots + \varepsilon_N^2.$$

and

$$h = \sqrt{2\frac{\varepsilon_1^2 + \varepsilon_2^2 + \ldots + \varepsilon_N^2}{N}}. \quad (32)$$

Value

$$\mu = \sqrt{\frac{\varepsilon_1^2 + \varepsilon_2^2 + \ldots + \varepsilon_N^2}{N}} \quad (33)$$

he is called root-mean-square error of a series of measurements or the simply mean error of a series of measurements.

Thus, the formula, which represents the law of Gauss, will take the form

$$dp = \frac{1}{\mu\sqrt{2\pi}} e^{-\frac{x^2}{\mu^2}} dx. \quad (34)$$

The obtained expression of the law of the distribution of the random errors can be represented in the form of curve (Fig. 7).

Calculations show that magnitudes of error in the half of measurements (0.5N) are located from -0.674μ to $+0.674\mu$. The form of

the curve of the law of Gauss depends on the value of root-mean-square error of a series of measurements. Many researchers experimentally check the law of Gauss and will confirm his correctness. In the presence of noticeable systematic errors, the curve is misaligned and becomes unsymmetric relative to the origin of coordinates.

Applying the law of Gauss during processing of the results of experiments, it is possible to draw a conclusion about the probable value of the measured value. Let us assume that one and the same value is measured under the constant/invariable conditions N once one and the same instruments and is obtained a series of its values

$$l_1, l_2, \ldots, l_N.$$

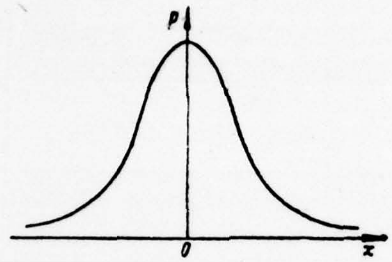

Fig. 7. Law of distribution of random errors.

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To what will be the equally probable value of the measured value? Let it be equal to L. Then errors are equal to

$$\varepsilon_1 = l_1 - L.$$
$$\varepsilon_N = l_N - L.$$

The probability of the joint appearance of values $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_N$, as is evident of previously demonstrated theorem and the law of Gauss, it is proportional

$$\left(\frac{1}{h\sqrt{\pi}}\right)^N e^{-\frac{1}{h^2}\left(\varepsilon_1^2 + \varepsilon_2^2 + \ldots + \varepsilon_N^2\right)}.$$

Moreover probability will be greatest, when the value of sum $\sum_1^N \varepsilon_i^2$

is minimal. This sum can be presented in the form

$$\sum_{1}^{N} \varepsilon_i^2 = V = (l_1 - L)^2 + (l_2 - L)^2 + \ . \ . \ . + (l_N - L)^2$$

and to find the condition of the minimum of its value

$$\frac{dV}{d\alpha} = 2[(l_1 - L) + (l_2 - L) + \ . \ . \ . + (l_N - L)] = 0,$$

whence

$$\alpha = \frac{l_1 + l_2 + \ . \ . \ . + l_N}{N} . \qquad (35)$$

This means that, if produced N of measurements, then the most probable (true) value of the unknown quantity will be arithmetic mean of this series of measurements.

It is interesting to note that the researchers intuitively apply the law arithmetic mean long before appearance law of Gauss.

Processing the results of direct measurements.

In this section is given the order and formulas (without conclusion/derivations) for processing of the results of direct measurements with the aid of the method of least squares. Usually as true value (independent of the number of measurements), they accept

arithmetic mean of results N of measurements, determined by formula (35). It must be noted that in this formula substitute values l_1, l_2 and so forth, already freed from systematic errors and errors. The latter is possible easily to reveal/detect with the survey of the results of experiments.

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If N $\geqslant$ 10, then is estimated also the accuracy of measurements. First of all are estimated residual errors according to the formula

$$v_i = l_i - L \tag{36}$$

and an average quadratic error in the result of measurements according to the expression

$$\sigma = \sqrt{\frac{v_1^2 + v_2^2 + \ldots + v_N^2}{N(N-1)}}. \tag{37}$$

After this they calculate the greatest possible error in the result of the measurements

$$\Delta_{max} = 3\sigma \tag{38}$$

and the probable error in the result of the measurements

$$\rho = 0{,}6745\,\sigma. \tag{39}$$

Value ρ divides the field of errors by two equal parts, i.e., 0.5N it lie/rests within interval/gap $\pm\rho$. The final result of measurements he is record/written in the following form:

$$L_p = L \pm \rho. \tag{40}$$

Processing the results of indirect measurements.

Many values during testing of engines or their cell/elements are determined indirectly by calculation according to the data of direct measurements. Thus, for instance, power of turboprop engine on shaft is calculated according to the formula

$$N_e = \frac{M_{кр} n}{716{,}2} \quad hp,$$

where $M_{кр}$ is the torsional moment;

n - the revolutions of propeller shaft.

Values $M_{кр}$ and n are measured directly during tests.

Thus, the power of engine is determined indirectly according to the results of direct measurements. The most reliable value N_e is obtained, if value $M_{кр}$ and n are undertaken for calculation as arithmetic mean of a series of measurements.

Processing the results of indirect measurements is carried out as follows.

It is required to find value

$$P=f(x,y,z)$$

according to the results of direct measurements x, y, z. Values x, y, z are defined as arithmetic mean of a series of measurements.

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For determining a relative error in the indirect measurement of value P, apply the formula

$$\bar{\rho}=\frac{1}{P}\sqrt{\left(\frac{\partial P}{\partial x}\right)^2\xi_x^2+\left(\frac{\partial P}{\partial y}\right)^2\xi_y^2+\left(\frac{\partial P}{\partial z}\right)^2\xi_z^2}, \qquad (41)$$

in which

$\frac{\partial P}{\partial x}, \frac{\partial P}{\partial y}, \frac{\partial P}{\partial z}$ - the particular derivatives P on arguments x, y, z;

ξ_x, ξ_y, ξ_z - absolute errors in the results of direct measurements of values x, y, z.

Example. It is required to find the power, transferred by screw/propeller of TVD, if it is known that the torsional moment

$M_{кр}=3581\pm36$ kg-m the number of revolutions of shaft n = 1000 ± 10 r/min.

The amount of the power, transferred to screw/propellers, is calculated according to the formula

$$N_e=\frac{M_{кр}n}{716,2}.$$

For determining relative probable error, we find the partial derivatives

$$\frac{\partial N_e}{\partial n}=\frac{M_{кр}}{716,2};\quad \frac{\partial N_e}{\partial M_{кр}}=\frac{n}{716,2}.$$

Then, after multiplying partial derivatives by probable absolute errors Δn and $\Delta M_{кр}$ and after substituting for n and $M_{кр}$ their numerical values, from formula (41) let us find the probable relative error

$$\bar{\rho}=\frac{1}{N_e}\sqrt{\left(\frac{\partial N_e}{\partial n}\right)^2\Delta n^2+\left(\frac{\partial N_e}{\partial M_{кр}}\right)^2\Delta M_k^2}=$$
$$=\frac{716,2}{M_{кр}n}\sqrt{\left(\frac{M_{кр}}{716,2}\right)^2\Delta n^2+\left(\frac{n}{716,2}\right)^2\Delta M_{кр}^2}=$$
$$=\sqrt{\left(\frac{\Delta n}{n}\right)^2+\left(\frac{\Delta M_{кр}}{M_{кр}}\right)^2}=\sqrt{\left(\frac{10}{1000}\right)^2+\left(\frac{36}{3581}\right)^2}=0,014.$$

Thus, a probable relative error in the result of indirect measurement is 1.4o/o.

Value

$$N_e = \frac{M_{\text{кр}} n}{716,2} = \frac{3581 \cdot 1000}{716,2} = 5000 \text{ hp.}$$

Absolute probable error

$$\rho = \rho N_e = 5000 \cdot 0,014 = 70 \text{ hp.}$$

Final result must be recorded

$$N_e = 5000 \pm 70 \text{ hp.}$$

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Chapter III.

MEASURING METERS AND DEVICES.

In this chapter are examined the methods of the measurement of the parameters, which characterize work of VRD, the descriptions of instruments and measuring devices, widely applied in practice laboratories and experimental stations.

In the practice of scientific investigations increasing propagation receive also other methods and the instruments, which ensure either the increased accuracy of measurements or the measurement of the values, not determined during plant tests. So, for research on flows are applied the optical methods of studies and measurements - shadow, interferometric, spectral absorption. For speed measurement of flows, finds a use the method of tracing by

ions, the glowing particles, electric spark. During measurement of high temperatures, apply the methods of reversal of spectrum lines, pyrometric, etc. Considerable development will receive the study technique of burning by the method of straight line and schlieren-photography and interferometric measurement.

Survey/coverage of the scientific methods of study the reader can find in specialized literature [1].

FOOTNOTE [1]. Collection the "physical methods of measurement in gas dynamics and during burning", translation/conversion edited by Yu. F. Dityakin, IL, 1957. ENDFOOTNOTE.

1. Pressure measurement.

During the tests of jet engines, are measured the following pressures: barometric - by barometers, evacuation/rarefaction - by vacuum gauges, overpressure above the environment - by manometers and the pressure differentials - by differential manometers. In practice, however, all pressure devices or their jump/drops they are conditionally called manometers. For the measurement of the constant

or slowly changing pressures widest use will receive liquid, spring and piston gauges.

The idea of the liquid manometer in which the pressure or pressure difference is measured by the liquid column, proposed for the first time in 1640 by E. Torricellis. The spring pressure valves are created considerably late by R. Shints (1846) and by Ye. Bourdon (1848). The first diaphragm manometer is designed into 1847 by V. Vaydl.

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Liquid manometers.

Wide application they will find three types of the liquid manometers: U-shaped, single-tube (cup) and micromanometers. The schematic of a U-shaped manometer is given to Fig. 8.

Let us examine work of manometer. In two glass tubes, connected together below, is poured the liquid. To free jets, are conducted pressures p_1 and p_2. Then the weight of column h of liquid balances pressure difference

$$p_2 - p_1 = \gamma h. \quad (42)$$

where γ is the specific gravity/weight of closing liquid;

h - the measured pressure differential.

For determining a precise value of jump/drop p_2-p_1, it is necessary to correct for the effect of ambient temperature for the length of the scale, the specific gravity/weight of liquid and capillarity. A change in the size/dimensions of glass tube does not affect value h.

Real jump/drop can be determined by the measured jump/drop h by the formula

$$h_{\text{д}}=\frac{1+\alpha(t-t_0)}{1+\delta(t-t_0)}h, \qquad (43)$$

where α is a coefficient of the linear expansion of material of the scale;

δ - the volumetric expansion coefficient of closing liquid;

t - the ambient temperature in the torque/moment of measurement;

t_0 - standard temperature at which $h_{\text{д}}$ and h coincide (value t_0

= 20°C).

Value α for brass $0.16 \cdot 10^{-6}$ 1/deg, for glass $0.08 \cdot 10^{-6}$ 1/deg and for steel $0.11 \cdot 10^{-6}$ 1/deg.

The properties of the most frequently used in manometers liquids are given in Table 1 on page 30.

It must be noted that usually the tubes from which are manufactured the U-tube gauges, have variable inner diameter. This can lead to the error due to different surface tension in the elbows of tube. However, as show calculations, these errors are small. Therefore manometers with the calibrated tubes are applied only during very precise measurements.

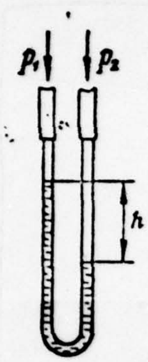

Fig. 8. Schematic of the U-tube gauge.

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Capillary corrections depend on the size/dimension of the diameter of tube and are calculated according to the formulas:

for the water

$$\Delta h_{к} = -\left(\frac{32,26}{d} - \frac{1}{6} d\right) \text{мм.} \qquad (44)$$

for the alcohol

$$\Delta h_{к} = -\left(\frac{12,90}{d} - \frac{1}{6} d\right) \text{мм,} \qquad (45)$$

for mercury

$$\Delta h_{\kappa} = +\left(\frac{6,45}{d} - \frac{1}{6} d\right) мм, \quad (46)$$

where d is a diameter of tube in mm.

An essential shortcoming in the U-tube gauges consists of the necessity to record the liquid level immediately in two tubes. The single-tube manometer whose schematic is given on Fig. 9 does not have this shortcoming. The measured jump/drop

$$h\gamma = p_2 - p_1.$$

During level measurement of liquid in reservoir is depressed, and in tube it is raised. So that it would be possible to disregard lowering the level in reservoir and measure h $\leqslant$ 1000 mm Hg with an accuracy to 0.1o/o, the ratio of the diameter of reservoir to the inner diameter of tube must be not less than 32.

During the use of single-tube manometers in the majority of cases, it is necessary to correct for capillarity. Thus, for instance, if $p_2 - p_1$ = 100 kgf/m² or, that one and the same, 100 mm H_2O, then with the diameter of tube d = 4 mm an increase in the water level in tube will be 7.4 mm, and the error in measurement will prove to be equal to 7.4o/o.

Table 1.

Property of working fluids.

(1) Наименование рабочей жидкости	(2) Химическая формула	(3) Удельный вес при 20° С $Г/см^3$	(4) Коэффициент объемного расширения при температуре 20° С
(5) Ртуть	Hg	13,547	$18 \cdot 10^{-5}$
(6) Вода	H_2O	0,998	$21 \cdot 10^{-5}$
(7) Керосин	—	~0,800	$\sim 95 \cdot 10^{-5}$
(8) Спирт этиловый (96%)	C_2H_5OH	0,790	$110 \cdot 10^{-5}$
(9) Четыреххлористый углерод	CCl_4	1,580	124.10^{-5}

Key: (1). Designation of working fluid. (2). Chemical formula. (3). Specific gravity/weight with 20°C g/cm³. (4). Volumetric expansion coefficient at temperature of 20°C. (5). Mercury. (6). Water. (7). Kerosene. (8). Ethyl alcohol (96o/o). (9). Carbon tetrachloride.

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For the measurement of small pressure differentials, which do not exceed 200 mm H_2O, are applied the micromanometers with inclined

tube (Fig. 10). It is obvious that

$$p_2 - p_1 = \gamma l \sin \alpha \quad (47)$$

(it is considered that the correction for value l is introduced).

During the application/use of manometers, one should limit the maximum values of pressure from the conditions of the strength of tubes. The limiting values of the pressure by which are destroyed the glass tubes, are given in Table 2.

One of the methods of fastening tubes it is shown to Fig. 11. This joint works well to 25 kgf/cm².

The application/use of liquid manometers for the measurement of small pressure differentials (to 0.1 kgf/cm²) is completely justified, since as working fluid can be applied water, alcohol and kerosene.

The measurement of large pressure differentials with the aid of liquid manometers is extremely undesirable, since for a decrease in the size/dimensions it is calm manometers is is commonly used mercury. The pairs of mercury are harmful and are caused in certain cases the heavy poisonings of the service personnel.

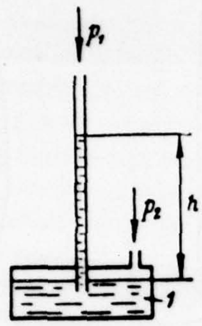

Fig 9.

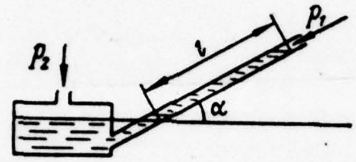

Fig. 10.

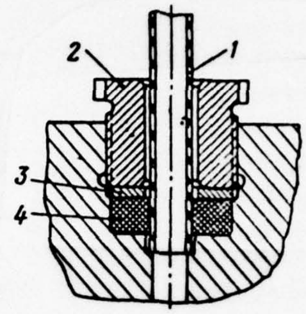

Fig. 11.

Fig. 9. Schematic of single-tube manometer. 1 - reservoir for liquid.

Fig. 10. schematic of micromanometer.

Fig. 11. Joint of glass tube with branch. 1 - tube, 2 - sleeve nut, 3 - thrust ring, 4 - packing/seal.

Tables 2.

Value of ultimate pressure in kgf/cm² for glass tubes.

Table 2.

Value of ultimate pressure in kgf/cm^2 for glass tubes.

(1) Толщина стенки мм	(2) Внутренний диаметр трубки в мм						
	1	2	3	4	5	6	7
1	—	310	280	230	220	150	140
2	570	—	340	—	330	240	220
3	560	460	420	400	—	—	230
4	—	450	—	400	310	320	280

Key: (1). Wall thickness mm. (2). Inner diameter of tube in mm.

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Spring pressure valves.

They distinguish three forms of the spring pressure valves: tubular, membrane/diaphragm and bellows.

On Fig. 12, is represented the schematic of spring tubular manometer. Spring 1 is the tube with oval cross section, inside which will be fed the measured pressure through branch 5. During the supplying of pressure, oval cross section attempts to be converted

into circular, spring 1 is straightened and with the aid of buckling 2 turns gear quadrant 3, which is located gear 4. On the axis with gear, it is attached rifleman/gunner. For the elimination of clearances and creation of interference in transfer, the axle/axis of arrow/pointer is twisted by very weak cylindrical spring.

For the manufacture of tubes, are applied the phosphor bronze, brass and stainless steel. Are most commonly used tubes from the phosphor bronze - material sufficiently strong under normal conditions, stable against corrosion and well yielding to treatment.

Steel tubes are applied in measurement of high or sharply changing pressures. Tubes made of the stainless steel are applied during pressure measurement of agressive media.

For example, for the tubes of acetylene manometers it is not possible to apply the material, which contains more than 70o/o copper, since in this case can be formed explosive joint - copper acetylide.

The tubes of the manometers, intended for pressure measurement of hydrogen, manufacture from hydrogen-resistant steel, which contains carbides with the alloying cell/elements.

On the manometers, intended for the measurement of pressures, acetylene and so forth, are made label on dial - "oxygen", "acetylene", etc.

Furthermore, manometer for pressure measurement of acetylene is painted in white color, for the measurement of pressure - in azure color, for pressure measurement of hydrogen - in dark green color, and for pressure measurement of ammonia - in yellow.

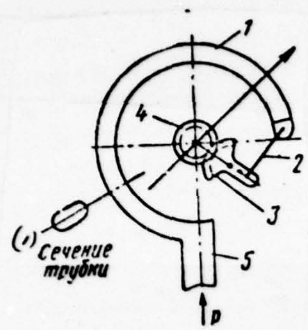

Fig. 12. Schematic of tubular manometer. 1 - spring, 2 - carrier, 3 - sector, 4 - gear, 5 - branch.

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Wide application find also diaphragm manometers (Fig. 13). Pressure p_1 is fed to housing 1, closed by corrugated diaphragm 2 (are applied also flat diameters). Diaphragm/membrane is deflected through the transfer, which consists of strut 3, carrier 4, sector 5 and gears 6, it turns the showing arrow/pointer.

The advantage of such manometers is low sensitivity to buffeting and ease of fabrication; a disadvantage of them is the increased sensitivity to a change in the ambient temperature. The diaphragm manometers are manufactured for pressure measurement within limits of

0.2-30 kgf/cm^2.

For the measurement of small pressure differentials are applied the bellows manometers (Fig. 14). Pressure p_1 is fed to housing 1 and compresses bellows 2. The deformation of bellows is transferred to gear. The arrow/pointer, which sits in line with gear, indicates the value of the measured quantity. The bellows manometers are utilized for the measurement of comparatively small jump/drops from 0 to 5 kgf/cm^2.

On aircraft and at experimental stations wide application will obtain electrical remote-transmitting manometers. This is common spring (membrane/diaphragm) manometers, with remote electrical transmission of measuring data. To Fig. 15, is given the schematic of the electrical remote-transmitting manometer, used during pressure measurement of fuel/propellant and oil.

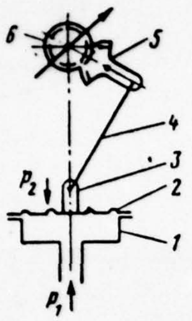

Fig. 13.

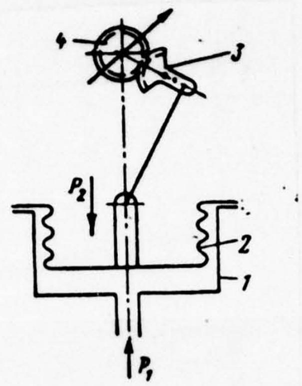

Fig. 14.

Fig. 13. Schematic of the diaphragm manometer. 1 - housing, 2 - diaphragm/membrane, 3 - strut, 4 - carrier, 5 - sector, 6 - gear.

Fig. 14. Schematic of the bellows manometer. 1 - housing, 2 - bellows, 3 - Sector, 4 - gear.

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Manometer feeds from mains of direct current with stress 27 + 2.7 V. The receiver of manometer is installed on engine, and indicator - on instrument panel; are connected they with the aid of wire/conductors.

The measured pressure is fed to the bellows. The deformation of box is transferred to lever 4 on which is attached brush 5, which slides on rheostat ab. Rheostat ab and brush are included in bridge circuit of logometer. During a change in the resistance R_x and R_y (as a result of the movement of brush 5) the current strength i_1 and i_2 is changed, which leads to change of the magnetic flux within the framework I and II and rotation of the needle of indicator, connected with magnet M.

In the diagram of logometer, are included fixed resistors R_1 and R_1 and tuning resistance r_R. Materials of the compensating resistance R'_3 and R''_3 are selected so that the work of instrument does not affect the temperature of medium.

An advantage of electrical remote-transmitting manometer lies in the fact that in its construction do not enter the tubes, which transmit pressure. The latter complicate installation and break from vibrations.

The kinematic pickup circuit electrical remote-transmitting manometer is shown to Fig. 16. The measured pressure will be fed to the sensor through branch 1 and is absorbed by diaphragm/membrane 2. The deformation of diaphragm/membrane is transferred with the aid of stock/rod 4 rocker 12 to carrier 9 on which is attached brush 6.

Brush 6 is moved on rheostat-5, as a result of which is changed resistance.

The indicator of manometer is the logometer whose kinematic diagram is shown to Fig. 17. In this logometer of the framework, are fixed, and magnet is mobile. Magnet 1 is made from the alloy of Alnico and it is fastened on the axis 2. Steel axle/axis 2 concludes with cores 5, which rest on bearing and step bearing 12 of the stone.

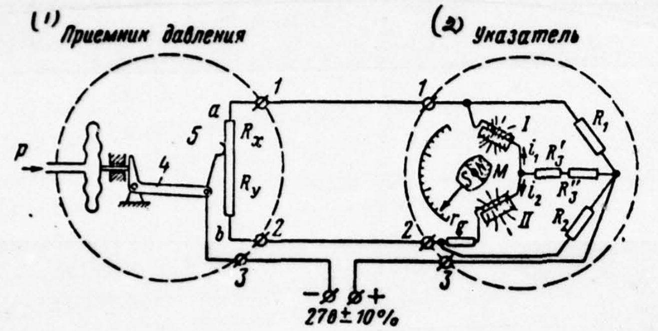

Fig. 15. Schematic diagram of electrical remote-transmitting manometer. 1, 2, 3 - the contacts of teletransmission and mains, 4 - lever, 5 - brush, ab - rheostat, R_x, R_y - the variable resistors of rheostat; R_1, R_2 - fixed resistors, r_g - tuning resistance, I, II - the framework, R'_3, R''_3 - compensating resistance.

Key: (1). Pressure receiver. (2). Indicator.

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Mobile magnet is encircled by copper damper 11, in which it during oscillation/vibrations excites moments of resistance from eddy currents.

To damper are put on two pairs of framework 9 and 3,

arrange/located at an angle of 90° to each other. Permanent magnet 13 serves for the return of mobile system to zero position (with the connected current). The parts of indicator are fastened to housing 8 with the aid of struts 7, passing through holes in damper. The housing, made from Permalloy, closes the magnetic field of instrument.

In recent years in laboratories and at experimental stations will win acceptance group pressure recording gauge - GRM-2, measuring the pressures, the evacuation/rarefactions or pressure differences is simultaneous at 20 points; the permissible error in recording part ±0.5o/o of the limiting value of the value, measured by appropriate sensing element.

The limits of measurement of pressures by manometer can be different depending on the rigidity of sensing elements - bellows. As a rule, in one instrument is allow/assumed two range of measurements.

Maximum capacities for a vacuum gauge from -1 to 0 kgf/cm², for a pressure and vacuum gauge from -1 to +19 kgf/cm² and for a manometer from 0 to 20 kgf/cm².

Measurement is realize/accomplished by the automatic spring cell/elements, constructed according to the type of weights.

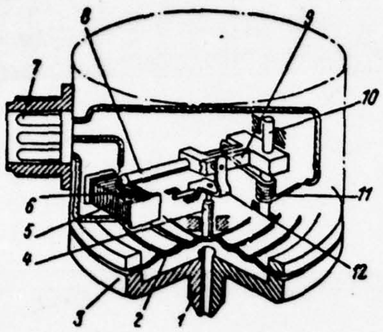

Fig. 16.

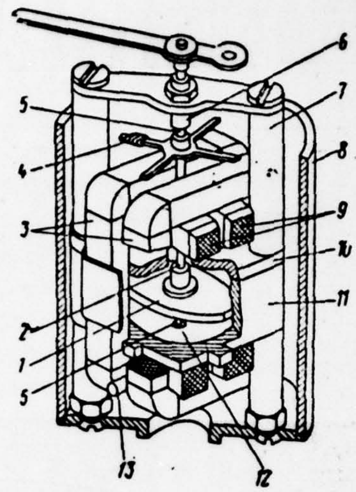

Fig. 17.

Fig. 16. Kinematic pickup circuit electrical remote-transmitting manometer. 1 - branch, 2 - diaphragm/membrane, 3 - base/root, 4 - stock/rod, 5 - rheostat, 6 - brush, 7 - plug-type connector, 8 - brush holder, 9 - carrier, 10 - axle/axis, 11 - spring, 12 - rocker.

Fig. 17. Kinematic diagram of logometer. 1 and 13 - magnets, 2 - axle/axis, 3 - the large framework, 4 - balancing small weights, 5 - cores, 6 - adjusting screw, 7 - strut, 8 - housing, 9 - low framework. 10 is a cap/cover of damper, 11 - damper, 12 - step bearing.

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The measured value depending on its character will be fed into one (in the case of the measurement of pressure or evacuation/rarefaction) or into two (during the measurement of a jump/drop in the pressures) bellows, which convert pressure or evacuation/rarefaction v.silu, that effects on lever. This force is automatically balanced by deformation force of spiral measuring spring. The amount of the deformation of measuring spring serves as the measure of the measured pressure. Instrument consists of twenty differing by device automatic spring cell/elements, united by the common drive also of series common/general/total mechanisms.

All the measuring cell/elements of instrument are mounted on common/general/total framework/body, moreover for convenience in the use they are assembled into two groups - on ten measuring cell/elements and to one mechanism of recording conditional numbers in each.

Let us examine work of measuring cell/element GRM-2 (Fig. 18). The measured pressure through cutting 1 is fed to bellows 2, establish/installed between fixed plate/bar 4 and lever 3. Because of the deformation of bellows, the lever can be turned about elastic hinge joint 5. Two bellows are placed in instrument for the

measurement of pressure difference.

Under effect of pressure, bellows 2 is dilate/extended and is caused the displacement/movement of lever 3. At the end of lever 3, there are two slide contacts 6, arrange/located between two fixed contacts 7. When lever 3 is located in equilibrium, contacts are extended. With decrease or increase of measured pressure, the lever differs from state of equilibrium, closing one or another pair of contacts, which is led to connection/inclusion of one of the two electromagnets 8. Electromagnet attract/tightens plate 9, attached on the housing of the axle/axis of roller 10, which in this case is introduced into the friction coupling with one of the continuously rotary disks of 11 group shafts 12. The direction of rotation of roller depends on that, with which disk it is engaged, which in turn depends on connection/inclusion of one of the two electromagnets. Group shaft is given to rotation by engine 13 through worm gear 14.

Roller 10 through worm gear 15 rotates the cylinder of visual screw/propeller 16 and screw/propeller 17. During the rotation of screw/propeller 17, nut 18 is moved on screw/propeller, changing tension of measuring spring 19 to as long as lever 3 it will not arrive to equilibrium state, and contacts 6 and 7 it is not extended, and electromagnet 8 is disconnect/turned off.

The greater the pressure differential in bellows, the greater must be the balancing force and the more the revolutions it will make a screw/propeller to the equilibrium of lever. The number of revolutions of screw/propeller proportional the pressure differential in bellows serves as the measure of this the pressure differential. Thus, at work of instrument lever 3 always is supported in equilibrium state.

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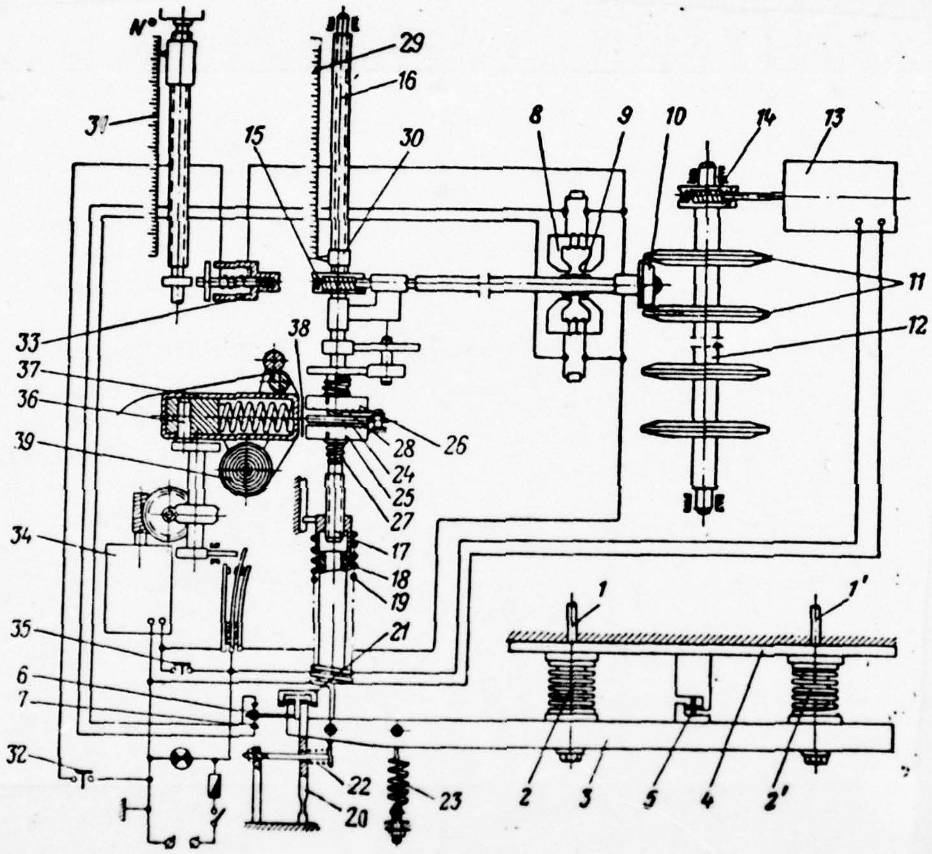

Fig. 18. Circuit of group pressure recording gauge. 1. 1' - feeder tubes, 2, 2' - bellows, 3 - lever, I - fixed plate/bar, 5 - elastic hinge joint, 6, 7 - contacts, 8 - electromagnet, 9 - plate, 10 -

roller, 11 - clutch plates, 12-group shaft, 13 - electric motor, 14, 15 - worm reducers, 16 - cylinder of visual screw/propeller, 17 - screw/propeller, 18-nut, 19-measuring spring, 20 - lever with leaf spring, 21 - thrust/rod, 22, 23 - spring, 24 - indicator 25, 26 - type waves, 27 - spring, 28 - reducer, 29 - the visual scale, 30 - indicator, 31 - dial face, 32 - the knob/button of the readjustment of conditional numbers, 33 - electromagnet, 34 - electric motor, 35 - the knob/button of the start of the printing mechanism, 36 - crank, 37 - carriage, 38 - tape, 39 - paper.

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For sensitization of instrument, lever 3 is equipped by the compensator of rigidity, which consists of lever 20, thrust/rod 21 with elastic hinge joints and spring 22 whose tension is regulated. The force of spring 22 is transferred to the measuring lever through the thrust/rod and elastic hinge joints.

In position of equilibrium of lever this force is directed through the point of its fluctuation and therefore it does not disturb balance. During the deflection of lever 3, position of thrust/rod 21 changes, due to which force direction does not coincide with the axis of rocking. The appearing torque/moment is applied to

lever 3 and affects to the side of its deviation. The value of torque/moment is proportional to the angle of deflection of lever. The tensile stress of spring 22 is establish/installed so that the torque/moment from the compensator of rigidity, which appears during the deflection of lever, would balance total torque/moment of all flexible couplings.

The presence of the compensator of rigidity raises instrument sensitivity, since for displacing the lever from position of equilibrium to closing of contacts is necessary very low force.

Besides measuring spring, to lever 3 is fastened spring 23 with the aid of which is created preliminary load on the lever, necessary in the case of work of instrument as pressure and vacuum gauge, and is regulated zero readings.

Readings at the necessary moments of time are recorded by the printing of the sections of the scales and indicators with paper tapes.

Transmission of measuring data to the scales of recording goes from screw/propeller 17. On the cylinder of screw/propeller, freely sit the indicator 24 and type waves 25 and 26 with the relief scales. Wheel 25, which has of 50 divisions, is held by spring 27 in the

detent of screw/propeller 17 and therefore it is rotated together with it. Type wave 26, which has twenty of divisions, is connected with the screw/propeller through reducer 28. With each revolution of screw/propeller, the wheel is turned to one division. When type wave 25 makes the complete revolution, wheel 26 is turned to one division. Thus, wheel 25 appears as the vernier of wheel 26. Indicator 24 with turning of screw/propeller remains fixed.

Besides the scales on type waves, the instrument has visual scales 29 with indicators 30 for continuous observation of the measured pressures.

Simultaneously with the measured values on paper tape is printed the number of instrument and the conditional numbers, which designate the numbers of measurement and mode/conditions, the time of measurement or any other factor. For this in instrument, there are two mechanisms of recording numbers with visual scales 31. The mechanism of the readjustment of conditional numbers is included in the work with electrical knob/button 32, closing the circuit of electromagnets 33.

Readings are recorded by the special mechanism which is driven by electric motor 34 and is included by knob/button 35. Electric motor 34 is set in motion through reducer cranks 36, connected with

carriage 37. In the complete revolution of cranks the carriage matches up typical wheels, is pressed to them coloring tape 38 and paper 39, and then rolls it over wheels; after which carriage it will move away and it returns to initial position. As a result on paper, remains the impression of the scales and indicator.

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Methods of the supply of pressure to manometers.

For the supply of pressure from sensors to manometers, are are commonly used copper, rubber and plastic tubes. During the measurement of pressures exceeding 3 kgf/cm², one should apply copper tubes with soldered or nipple connections. Rubber tubes connect up manometers with the aid of standard joints. When is measured comparatively large overpressure, is recommended the part of rubber tube, which is located on nipple, to bind with copper wire (double loop) or to clamp by clamping collar.

During the measurement of rarefaction, common rubber tubes can stick together and then one should pass to vacuum rubber or copper tubes. If in the system being investigated are fluctuations of

pressure, then them it is possible during transfer to instrument to decrease by the start of capillaries and damping volumes.

It is completely necessary prior to the beginning of experiments, and also after their conducting to check the measuring systems of pressure on airtightness. Leak check should be carried out with overpressure or theevacuation/rarefaction, greater than during experimentation.

To Fig. 19, it is given one of the possible diagrams of the constant control of the airtightness of the measuring system of the pressure. During testing of system it is necessary to close tap/crane 1: if there are leakages in the system between tap/crane 1 and the manometer, then through the liquid (tap/crane 2 is opened, pouring tap/crane 3 - is closed) they will begin to pass gas bubbles.

In the case of overpressure airtightness can be tested, wetting the suspected places by soap water and observing the behavior of film.

Accuracy/precision of measurements and calibration of manometers.

During tests of VRD liquid manometers they do not usually calibrate. The accuracy of measurements is determined by the introduction of the corresponding corrections and by the value of pressure differential.

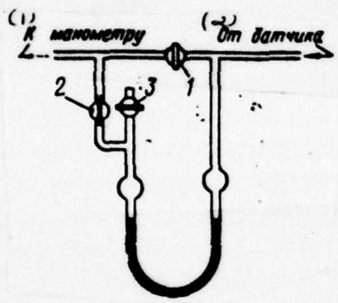

Fig. 19. Diagram of the control of the airtightness of the system of the measurement of pressure. 1 - the gauge cock, 1 - the bypass cock, 3 - pouring tap/crane.

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The spring pressure valves calibrate with the aid of the control or specimen spring and piston gauges. Fig. 20, shows the schematic of piston press for the calibration of spring manometers.

Spring manometers of general purpose (working) are manufactured of five classes of accuracy: 0.5, 1.0, 1.5, 2.5 and 4. Control manometers serve for precise measurements and testing of working manometers. They are more precise and are produced two classes of precision - 0.5 and 1.0.

Specimen spring pressure valves serve for testing of control and working manometers, and also for laboratory measurements; they are produced two classes of precision - 0.20 and 0.35, i.e., an error of measurement comprises not more than ±0.20 and ±0.35o/o of the upper limit at ambient temperature +20±5°C.

Standard piston gauges up to a pressure of 50 kgf/cm² provide the accuracy of measurements with error not more than ±0.01o/o from

the measured pressure, and up to a pressure of 250 kgf/cm², are not more than ±0.02o/o of the measured value.

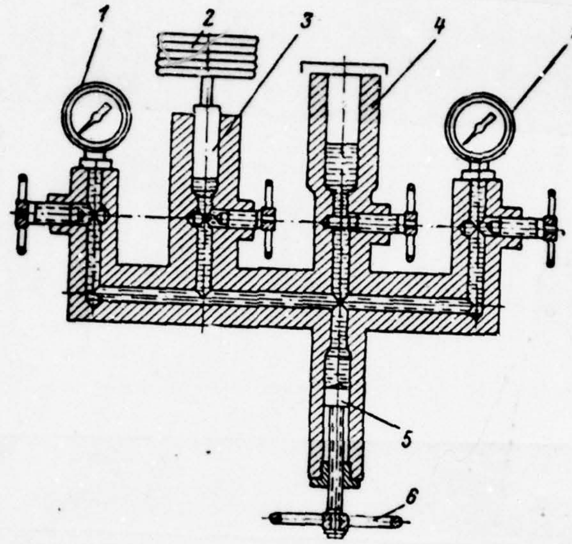

Fig. 20. Diagram of piston gauge. 1 - the calibrated manometers, 2 - weight, 3 - plunger, 4 - reservoir for a liquid, 5 - piston, 6 - handwheel.

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Specimen piston gauge up to a pressure of 50 kgf/cm² provides the accuracy of measurements with error not more than ±0.02o/o, also, for the pressures of high 50 kgf/cm² with error not more than ±0.05o/o. Specimen piston gauges are used extensively for the calibration of control and specimen spring pressure valves.

Aircraft manometers give an error of measurement not more ±3o/o.

2. Temperature measurement.

By practical temperature scale is "International practical temperature scale 1948", accepted IX General conference on measures and weights. This scale is based on the constant, comparatively easily reproducible temperatures of the phase equilibrium which call standard points.

The subsequent conferences will introduce some changes into the temperature scale.

X General conference on measures and weights (1954) determined the temperature scale with basic standard point - the triple point of water to which corresponds temperature 273.16°K. The triple point of water - equilibrium point of water in solid, liquid and vapor phase - can be reproduced with error not more than 0.0001°C.

XI General conference on measures and weights (1960) recommends as additional standard point the solidification point of zinc (419.505°C).

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Table 3 gives given data on the absolute accuracy of realization and fidelity of the practical scale.

It is accepted at present that the deviation of the values of standard points from absolutely precision dial of temperatures does not exceed $\pm 0.02°$ at $-182.97°C$, $\pm 0.10°$ at $444.60°C$ so forth (see Table 3).

Table 3. The standard points of the temperature scale at the pressure 760 mm Hg.

(1) Реперная точка	t °C	Точность осуществления (2) °C	Точность воспроизведения (3) °C	Измерительный прибор (4)
Кипение кислорода (5)	−182,97	±0,02	±0,020	Термометр сопротивл (6)
Тройная точка воды (основная реперная точка) (7)	0,01	—	±0,0001	То же (8)
Кипение воды (9)	100,00	—	±0,003	.
Кипение серы (10)	444,60	±0,10	±0,005	.
Затвердевание серебра (11)	960,8	—	—	Термопара (12)
Затвердевание золота (13)	1063,0	±1	±0,050	.

Key: (1). Standard point. (2). Accuracy/precision of realization. (3). Fidelity. (4). Measuring meter. (5). Boiling oxygen. (6). Thermometer resist. (7). The triple point of water (basic standard point. (8). The same. (9). Boiling water. (10). Boiling sulfur. (11). Solidification of silver. (12). Thermocouple. (13). Solidification of gold.

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The task of the reproduction of standard points is incomparably simpler than the task of the realization of precision dial and, as fault from Table 3, is solved in temperature range, large 0°C, it is considerably more precise.

The most precise thermometric work are performed with the aid of the gas thermometers, filled by hydrogen and helium. Their application/use for the precise measurements of temperature is based on the use of equation of Clapeyron with corrections.

During test work of VRD, are applied:

1) liquid thermometers - for the measurement of ambient temperature on stand;

2) manometric thermometers - for the measurement of the temperature of oil (is rare);

3) resistance thermometers - for the measurement of the temperature of air during the analysis of entries and compressors, oil and fuel/propellants;

4) thermocouple - for the measurement of the temperatures of gases and surfaces of the parts of engine.

Liquid thermometers.

Liquid thermometers are very simple and are characterized by the high accuracy of measurement.

The operating principle of liquid thermometers is based on the thermal expansion of liquid in glass. Therefore temperature measurement by these thermometers is reduced to observation of a change in the visible volume of liquid. More frequently are encountered the thermometers of two basic types: (Fig. 21).

Let the level of liquid with 0°C stand to scale zeros. During temperature, change is changed the volume of liquid and glass reservoir of thermometer. The visible expansion of liquid ΔV is equal to a difference in the expansion of liquid $\Delta V'$ and of thermometer $\Delta V''$. It is obvious

$$\Delta V=\Delta V'-\Delta V'', \tag{48}$$

whence

$$\frac{1}{V_0}\frac{dV}{dt}=\frac{1}{V_0}\frac{dV'}{dt}-\frac{1}{V_0}\frac{dV''}{dt}, \tag{49}$$

where V_0 is a volume of liquid with 0°C.

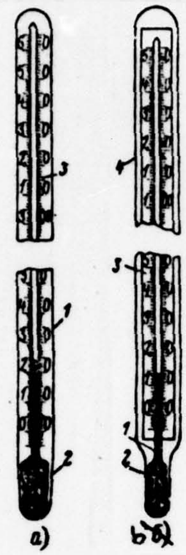

Fig. 21. Thermometers. a) stick, 1 - thick-walled capillary, 2 - reservoir, 3 - the scale, plotted/applied on the surface of capillary. b) with the inserted scale. 1 - capillary, 2 - reservoir, 3 - the scale, plotted/applied on plate to plate from frosted glass, 4 - protective clothing.

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After introducing the concepts: the coefficient of the visible expansion of the liquid

$$\alpha = \frac{1}{V_0} \frac{dV}{dt},$$

of the coefficient of the expansion of the liquid

$$\alpha' = \frac{1}{V_0} \frac{dV}{dt},$$

of the coefficient of the expansion of the glass

$$\alpha''=\frac{1}{V_0}\frac{dV''}{dt},$$

we will obtain the formula

$$\alpha=\alpha'-\alpha''. \qquad (50)$$

It is obvious that

$$dl=\alpha\frac{V_0}{f}dt, \qquad (51)$$

where dl is a change in liquid level in capillary;

f - the cross-sectional area of capillary.

At data α, V_0 and dt value dl the greater, than less f, i.e., the thermometer sensitivity dl/dt the greater, the greater the ratio V_0/f.

The properties of the liquids, used for filling of thermometers, are given in Table 4.

Mercury thermometers are applied for the measurement of temperatures to 750°C; in this case the space of the capillary above mercury is filled with nitrogen or another inert gas, which has pressure of approximately 70 atm.

Table 5 gives corrected values of the coefficient of the visible expansion of mercury for the different types of glass from which are

manufactured the capillary tubes of thermometers.

With technical the precision determination of temperature it is desirable to load thermometer into medium before the calculated division. If this is impossible, then one should introduce correction for the protruding column.

Table 4. Properties of thermometric fluids with 760 mm Hg.

Вещество (2)	Химическая формула (3)	Коэффициент расширения при 18° C (4)	Температура в °C (1)			
			(5) затвердевания		(6) кипения	
			от (7)	до (8)	от (7)	до (8)
Метиловый спирт (9)	CH_3OH	0,001220	—93,9	—97,8	+64,2	+66,0
Этиловый спирт (10)	C_2H_5OH	0,001100	—111,8	—117,3	+77,7	+78,4
Пентан (чистый) (11)	C_5H_{12}	—	—130,8	—147,5	+36,0	+36,5
Толуол (12)	$C_6H_5CH_3$	0,001090	—92,4	—102	+102	+110,6
Ртуть (13)	Hg	0,000181	—38,87	—38,87	+356,7	+356,7

Key: (1). Temperature in °C. (2). Substance. (3). Chemical formula. (4). Coefficient of expansion with. (5). solidification. (6). boiling. (7). from. (8). to. (9). Methyl alcohol. (10). Ethyl alcohol. (11). Pentane (pure/clean). (12). Toluene. (13). Mercury.

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Fig. 22, shows the schematic of the setting up of basic (measuring) thermometer in tube and auxiliary for the introduction of correction. Auxiliary thermometer holds on basic by rubber clamping collars so that the reservoir of auxiliary thermometer would be the approximately halfway protruding column of the thermometric fluid of basic thermometer.

Fig. 22 O_1 and O_2, indicate zero thermometers. During the introduction of correction, it is assumed that the part of

thermometer t_1 and reservoir have temperature of medium t_c but the upper part of thermometer $t_2 - t_1$ has temperature $t_в$ (i.e. the temperature, shown by the auxiliary thermometer).

The actual temperature of medium is determined from the formula

$$t_c = \frac{t_2 - at_в(t_в - t_1)}{1 - a(t_2 - t_1)}. \qquad (52)$$

since α is actually a function of temperature. However,

Formula (52) - approximated, since α in the majority of the practical cases it it is possible to use, if value α is is taken at temperature $t_в$° C.

Manometric thermometers.

Manometric thermometers are liquid, steam and gas. The schematic of manometric thermometer is shown in Fig. 23. Reservoir (sensor of thermometer) 1 to 60o/o is filled by the easily vaporizing liquid (by methyl ether, methylchloride and so forth); which transmits vapor pressure capillary tube 2 is most frequently filled by the same liquid.

In view of the fact that between the temperature of reservoir and the vapor pressure of thermometric fluid there is no direct proportionality, the scale of thermometer proves to be nonuniform.

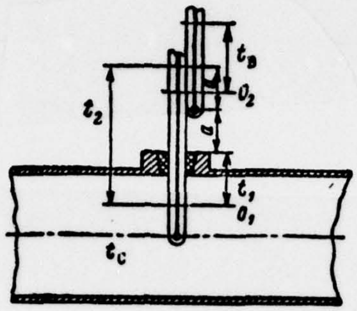

Fig. 22. Schematic of setting of basic and auxiliary thermometers.

Table 5.

(1) Сорт стекла	a_0^{100}
(2) Термометрический 16^{III}	$1{,}57 \cdot 10^{-4}$
(2) Термометрический 59^{III}	$1{,}64 \cdot 10^{-4}$
(3) Кварц	$1{,}79 \cdot 10^{-4}$
Термометрический (2) ГОСТ 1224—41	$1{,}58 \cdot 10^{-4}$

Key: (1). Type of glass. (2). Thermometric. (3). Quartz.

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As a result of the number of the shortcomings: the insufficient strength of capillary, low accuracy/precision, difficulty of repair, these thermometers, are almost completely displace/superseded

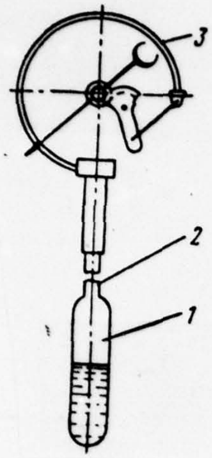
electrical.

Resistance thermometers.

The operating principle of resistance thermometers is based on a change in the electrical resistance of some conductors under the effect of temperature. Sensing element whose resistance is changed depending on temperature, is connected in the balanced bridge whose schematic diagram is represented in Fig. 24.

Sensing element of thermometer is resistance R_t. During temperature, change the value of resistance R_t changes, which is led to the disequilibrium of bridge, which is record/fixed by galvanometer G. Dial face is thoroughly calibrated into °C. Feed/supply of instrument is realize/accomplished from battery or another source of direct current.

Resistance thermometers make from platinum, copper, nickel, iron and special alloys. It should be noted that platinum is capable to long retain its physical properties. As a result of which, platinum resistance thermometer is applied for interpolation of international thermometric scale within limits from -180 to 660°C.



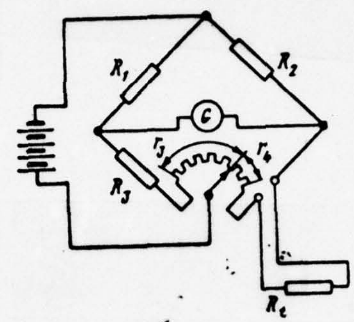


Fig. 23. Fig 24

Fig. 23. Schematic of manometric thermometer. 1 - the sensor of thermometer, 2 - the transmitting tube, 3 - temperature indicator (manometer).

Fig. 24. Schematic diagram of resistance thermometer with balanced bridge. R_1, R_2, R_3 are the fixed resistors. $r_3 r_4$ are the trim drag, R_t - the resistance of sensing element.

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Communication/connection between the temperature of medium t°C and resistance R_t in the range 0 to 1100°C with high

accuracy/precision is establish/installed by the equation

$$t=100\frac{R_t-R_0}{R_{100}-R_0}+\delta\left(\frac{t}{100}-1\right)+\gamma\frac{t}{100}\left(\frac{t}{100}-1\right)\left(\frac{t}{444.6}-1\right), \quad (53)$$

in which constant values R_0, R_{100}, δ and γ they are determined experimentally from standard points. Here R_0 and R_{100} resistance at temperatures of 0 and 100°C.

By roughness value of platinum can it serves the relation of resistance R_{100}/R_0; for platinum of the brand of the "Extra" first class R_{100}/R_0 = 1.389±0.0007.

Copper, utilized for resistance thermometers, has large temperature drag coefficient ($\alpha = 4.25\cdot10^{-3}-4.28\cdot10^{-3}$) and makes it possible to determine temperature resistance R_t according to the linear equation

$$R_t=R_0(1+\alpha t). \quad (54)$$

Shortcomings in copper are its low specific resistance (ρ = 0.017 $\Omega\cdot mm^2/m$) and the oxidizability, which limit the field of its application/use to temperature of 150°C.

Nickel possesses high temperature coefficient ($\alpha = 6.21\cdot10^{-3}-6.34\cdot10^{-3}$). However, nickel has the complex dependence of temperature coefficient on temperature, what is essential shortcoming.

Resistance thermometers and the limits of the measured by them temperatures are standardized (GOST 6651-59) and given in Table 6.

Fig. 25, shows a change of the ratio of resistance R_t to resistance R_0 depending on temperature for some metals.

The construction of the receiver of resistance thermometer is given in Fig. 26.

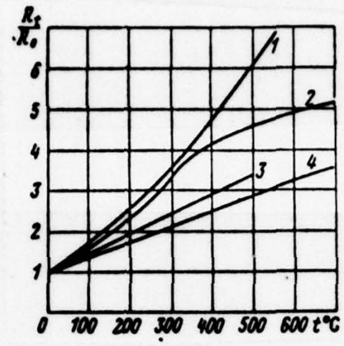

Fig. 25. Change of resistance of metals depending on temperature. 1 - gland, 2 - nickel, 3 - copper, 4 - platinum.

Table 6. Capacities of temperatures by the resistance thermometers ETP, ETM and ETN.

Материал чувствительного элемента термометра (2)	Условное обозначение термометра (3)	Пределы измерения температур в °C (1)	
		наименьший (4)	наибольший (4) 5
Платина (5)	ЭТП	—200	+500
Медь (6)	ЭТМ	—50	+150
Никель (7)	ЭТН	—50	+200

Key: (1). Capacities of the temperatures in °C. (2). Material of sensing element of thermometer. (3). The conventional designations of thermometer. (4). smallest. (5). Platinum. (6). Copper. (7). Nickel.

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Shielding tube 1 is made from the stainless steel, heat-sensitive element 3 is made from the nickel wire with a diameter of 0.05 mm and it is wound around mica plate 4.

Aviation resistance thermometers work from the source of direct current with stress 27±2.7c.

Thermoelectric thermometers.

The principle of temperature measurement by thermoelectric thermometers is based on the phenomenon of thermoelectricity, unearthed into 1958, by Russian academician F. Aepinus. This phenomenon is explained to the facts that all metals consist of the positively charged fixed ions and the free negatively charged electrons which can be likened to the free gas, filling the intermolecular space.

In different metals the density and the pressure of electron gas with the same temperature, is different. If we weld or to solder two wires A (copper) and B (platinum), as shown to Fig. 27, then

electrons from copper wire will begin to transfer/convert to platinum. Near joints 1 and 2 copper wire will be loaded positively, platinum - is negative. Appearing in joints 1 and 2 electrons of one material in another and with certain potential difference the process of the transition of electrons will be discontinued, since will set in dynamic equilibrium, i.e., a quantity of outgoing from this material electrons it will become equal to a quantity of those who come in.

If we heat joint 1 to temperature of t, in this case temperature t_0 of joint 2 it will remain constant/invariable ($t_0 < t$), then in the circuit, comprised of conductors A and B, will arise current, i.e., circuit it will become the generator of electric power. Conductors in the circuit in question are called of thermoelectrodes, and their joint - thermocouples.

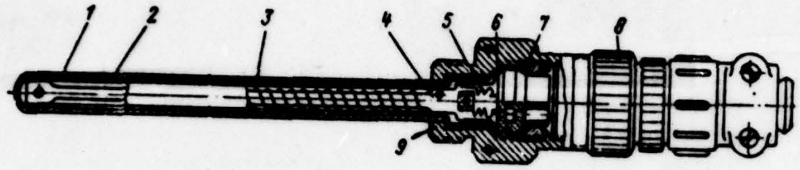

Fig. 26.

Fig 27.

Fig. 26. Receiver of resistance thermometer. 1 - shielding tube, 2 - isolation/insulation, 3 - heat-sensitive cell/element, 4 - mica plate, 5 - additional resistance, 6 and 7 - packing, 8 - plug-type connector, 9 - branch.

Fig. 27. Thermoelectric circuit.

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As will show numerous experiments, for a thermoelectric circuit is correct the equation

$$E_{AB}(t, t_0)=e_{AB}(t)+e_{BA}(t_0), \qquad (55)$$

where $E_{AB}(t,t_0)$ **is thermal-** e.m.f. in **of circuit in direction of flow from one A to** B,

$e_{AB}(t)$ are thermal- e.m.f. in joint 1;

$e_{BA}(t_0)$ - thermal- e.m.f. in joint 2 in direction of flow from one B to A.

With the equality of the temperatures of both joints thermal- e.m.f. of circuit, it is equal to zero, i.e., if

$$t=t_0,$$

then

$$E_{AB}(t, t_0)=0.$$

In this case

$$e_{BA}(t_0)=-e_{AB}(t_0)$$

and, therefore, equation (55) can be recorded thus:

$$E_{AB}(t, t_0)=e_{AB}(t)-e_{AB}(t_0). \quad (56)$$

Equation (56) makes it possible to determine temperature of t, if are known thermal-emf of circuit and temperature t_0, i.e., the temperature of the cold-soldered joint. Value $E_{AB}(t,t_0)$ can be measured with the aid of pyrometric millivoltmeter or potentiometer. Temperature t_0 of the cold-soldered joint it is desirable in the process of measurements to support with constant and strictly defined. Best of all joint 2 to place into medium, having temperature $t_{cp}=t_0=0°C$, for example into water with melting ice.

Materials of thermoelectrodes are selected so that value $E_{AB}(t, t_0)$ would be possibly larger.

Thus, the measurement of temperature of t in principle is possible with the aid of thermoelectric circuit (thermocouple), depicted on Fig. 27.

Quantity galvanometer in circuit thermal-e.m.f. can be included according to two schematics (Fig. 28). In the first schematic the galvanometer is included between cold-soldered joints 2 and 3, in this case joint 1 will be hot (see Fig. 28a).

In the second schematic the galvanometer is included in the breaking of electrode B, then in circuit joint 1 will be hot, 2 - cold, and 3 and 4 - neutral (see Fig. 28b) in circuit are identical.

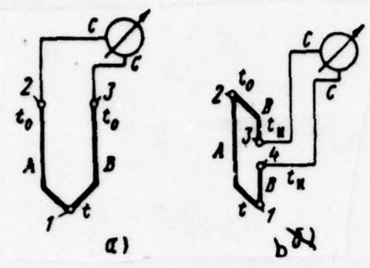

Fig. 28. Connection measuring meter into thermoelectric circuit.

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Thermal-e.m.f. of different circuits will be equal, if the total resistance of the corresponding wire/conductors and electrodes and temperature of cold and hot junctions of these circuits they will be also equal.

In fact, the circuit on Fig. 28a consists of three conductors A, B, C (presence of instrument does not change the correctness of the given conclusion/derivation). On the basis of the second law of thermodynamics with the equality of temperatures t_0 = t thermal-emf in circuit is equal to zero. That means that for this case it is possible to write:

$$e_{AB}(t)+e_{BC}(t)+e_{CA}(t)=0,$$

or

$$e_{BC}(t_0)+e_{CA}(t_0)=-e_{AB}(t_0). \quad (57)$$

If joint 1 has temperature of t, and joint 2 and 3 - temperature t_0, then

$$E_{AB}(t, t_0)=e_{AB}(t)+e_{BC}(t_0)+e_{CA}(t_0). \qquad (58)$$

After substituting of formula (58) the value of the sum $\underbrace{e_{BC}(t_0)+e_{CA}(t_0)}$ from formula (57), we will obtain

$$E_{AB}(t, t_0)=e_{AB}(t)-e_{AB}(t_0). \qquad (59)$$

As is evident, formulas (56) and (59) are identical; therefore it is possible to confirm that thermal- e.m.f by the developed circuit, shown in Fig. 28a and by initial circuit (Fig. 27) are equal.

For the circuit, depicted on Fig. 28b, is correct the equality

$$E_{AB}(t, t_0)=e_{AB}(t)+e_{BC}(t_{\text{н}})+e_{CB}(t_{\text{н}})+e_{BA}(t_0). \qquad (60)$$

After taking into consideration of the equality

$$e_{BC}(t_{\text{н}})=-e_{CB}(t_{\text{н}}) \qquad (61a)$$

and

$$e_{BA}(t_0)=-e_{AB}(t_0), \qquad (61b)$$

we will obtain

$$E_{AB}(t, t_0)=e_{AB}(t)-e_{AB}(t_0). \qquad (62)$$

Thus, and the circuit, given in Fig. 28b, will also prove to be equivalent initial (see Fig. 27).

It can seem that in schematic in Fig. 28a the temperature of cold-soldered joint 2 is equal to t_0', and joint 3 is equal to t_0. Then

$$E=e_{AB}(t)+e_{BC}(t_0)+e_{CA}(t_0'). \quad (63)$$

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Deducting equation (63) from (59), we will obtain

$$E_{AB}(t,t_0)-E=e_{BA}(t_0)+e_{CB}(t_0)+e_{AC}(t_0'). \quad (64)$$

After taking into consideration the equality

$$e_{AB}(t_0)=e_{AC}(t_0)+e_{CB}(t_0). \quad (65)$$

instead of the equation (64), let us record

$$E_{AB}(t,t_0)-E=e_{AC}(t_0')-e_{AC}(t_0). \quad (65)$$

Similar expressions can be obtained also in the case of the inequality of the temperatures of neutral joints 3 and 4 in schematic in Fig. 28b.

If the temperature of the cold-soldered joint of circuit a) or b) is changed and it will become equal to t_0', then thermal- e.m.f. also will be changed and it will become equal to

$$E_{AB}(t,t_0')=E_{AB}(t,t_0)-e_{AB}(t_0')+e_{AB}(t_0). \quad (66)$$

As is evident, equation (66) makes it possible to calculate $E_{AB}(t,t_0)$ on measured value $E_{AB}(t,t_0')$ and correction for the temperature of the cold-soldered joint: $e_{AB}(t_0')-e_{AB}(t_0)$.

The thermoelectric circuit, assembled according to schematic (Fig. 28b), can be used for the measurement of a difference in the temperatures.

In this case joints 1 and 2 are hot junctions, a difference in temperatures of which is determined. Joints 3 and 4 become cold, their temperature must be identical (its value it is indifferent).

Allowance for temperature of the cold-soldered joint is determined from the calibration graph of thermocouple (Fig. 29).

Let there be three materials A, B and C. Let us compose of them three thermocouples AB, AC, BC. For these thermocouples are accurate the equalities:

$$E_{AB}(t, t_0)=e_{AB}(t)-e_{AB}(t_0); \quad (67)$$

$$E_{AC}(t, t_0)=e_{AC}(t)-e_{AC}(t_0); \quad (68)$$

$$E_{BC}(t, t_0)=e_{BC}(t)-e_{BC}(t_0). \quad (69)$$

After taking into consideration the equation

$$e_{AB}(t_0)+e_{BC}(t_0)+e_{CA}(t_0)=0$$

and after making uncomplicated conversions, we will obtain

$$E_{BC}(t, t_0)=E_{BA}(t, t_0)-E_{CA}(t, t_0). \quad (70)$$

This equation makes it possible to conduct the calculation of any thermocouples from electrodes B, C, D and so forth, if are known

to their thermal- e.m.f. relative to electrode A, which is called normal. As normal thermoelectrode is applied chemically pure platinum.

Work of thermocouple and the capacities of the temperatures to a considerable degree depend on materials of thermoelectrodes; therefore it is very important correctly to select them.

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To materials are presented the following requirements:

1) thermal- e.m.f. with an increase in the temperature must increase (it is desirable - linearly);

2) value thermal- e.m.f. must be sufficiently large;

3) the coefficient of electrical resistance must be minimum, and electric conductivity high;

4) their physicochemical properties must not change under conditions of the normal of operation;

5) materials must be non-corrodible;

6) melting point must noticeably exceed that which is measured;

7) materials of thermoelectrodes must be sufficiently uniform.

Widest use received thermocouples from metals (noble/precious and ignoble), but for the measurement of high temperatures, sometimes are applied metallic thermoelectrodes paired with nonmetals, for example, tungsten-graphite.

The list of the most frequently used thermccouples is given in Table 7.

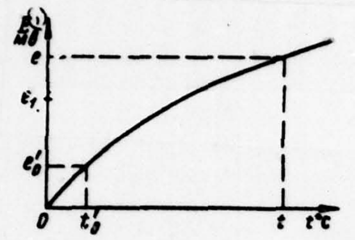

Fig. 29

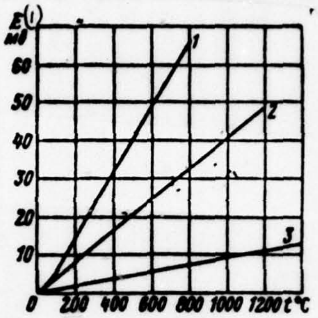

Fig. 30.

Fig. 29. Introduction of correction for temperature of cold-soldered joint. e_1 - measured emf, e_0' - value of emf, which corresponds to correction for the temperature of the cold-soldered joint, $e = e_1 + e_0'$ - total emf, t_0' - the temperature of cold-soldered joint, t - the measured temperature.

Key: (1). mV.

Fig. 30. Characteristics of thermocouples. 1 - Chromel-Copel. 2 - chromel-alumel, 3 - platinum-platinum-rhodium.

Key: (1). mV.

Table 7. Field of application of thermocouples.

(1) Термопара	Область применения (2) °C
Иридий-иридиеродий (3)	(4) до 2000
Платина-платинородий (5)	0÷1450
Хромель-алюмель (6)	—200÷1200
Хромель-копель (7)	—200÷800
Медь-константан (8)	—200÷350

Key: (1). Thermocouple. (2). Field of application. (3). Iridium-iridium-rhodium. (4). to. (5). Platinum-platinum-rhodium. (6). Chromel-alumel. (7). Chromel-Copel. (8). Copper-constantan.

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Fig. 30 gives characteristics of some thermocouples, used during testing of VRD. The device of thermocouples is described in the section, dedicated to measurements in flows.

The schematic of the generally accepted thermocouple pyrometer is represented in Fig. 31. Thermocouple 1 is connected with instrument with the aid of jumpers 2-4 and 3-5. If thermocouple is made from cheap materials, then wire/conductors 2-4 and 3-5 can be made from the same materials.

If the thermoelectrodes of thermocouple 1 are made from precious metals, appears the need for the jumpers which one should make from the cheap materials, which have the thermoelectric characteristics, close to thermo-electrode materials. It is always desirable so that the temperature of joints 2 and 3 will be identical.

Joints 4 and 5 are cold. They are removed from joints 2 and 3 a considerable distance, which simplifies the maintenance of their

temperature, equal to each other and to constant during experiment. Best of all these joints are immersed in test tubes with oil, and test tubes to place into thermostat with melting ice. If it is absent lethal dose, then the cold-soldered joints can be loaded into vessel with oil (temperature of which is checked), and during processing of measurement data to correct for the temperature of the cold-soldered joints.

For the measurement of the temperature in large quantities of points, are applied the schematics of the connection of thermocouples to instrument with the aid of switch. In view of the smallness of the current of thermocouples (0.5-1.0 mA) all wire/conductors must be thoroughly isolate/insulated. If the scale of electric measuring instrument is graduated in degrees, then the resistance of all pyrometers must be identical. Impedance matching is made with the aid of additional resistance 6. Instrument to joints 4 and 5 they connect by copper wire.

For the calculation of thermocouples, are necessary the data on materials of the thermal of electrodes, jumpers and on the resistance of instrument. Table 8 gives some data of the most widely used materials.

Sign "+" before the value thermoelectromotive force indicates that in the cold-soldered joint the current is directed from this material to platinum.

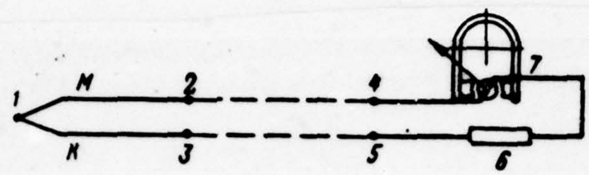

Fig. 31. Schematic of the thermocouple pyrometer. 1 - thermocouple, 2-4, 3-5 jumpers, 6 - additional resistance, 7 - galvanometer.

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Using data by Table 8, it is possible to determine thermoelectromotive force of some thermocouples and possibility of their application/use.

Example. It is necessary to determine thermoelectromotive force of chromel-alumel thermocouple with $t = 100°C$ and $t_0 = 0°C$, if they paired with platinum develop thermoelectromotive force

$$E_{X\Pi}(100°, 0°) = +2{,}70 \text{ мв}(1)$$
$$E_{A\Pi}(100°, 0°) = -1{,}38 \text{ мв}(1)$$

Key: (1). mV.

Thermoelectromotive force of chromel-alumel thermocouple will be

$$E_{XA}(100°, 0°) = E_{X\Pi}(100°, 0°) - E_{A\Pi}(100°, 0°) = +2{,}70 - (-1{,}38) = +4{,}08 \ mV.$$

Sign "+" indicates that in the cold-soldered joint the current flows from chromel to alumel.

For the measurement thermoelectromotive force of thermocouples, applies millivoltmeters and potentiometers.

Fig. 32, gives the schematic, which elucidates the essence of potentiometric (compensating) method. In this schematic resistance R is known, and source of current B supports current I during measurement by virtually constant. On the rheostat slides runner b to which is connected the source of current A and one clamp of thermocouple. Null instrument NP by one terminal is connected and to point a, but another to switch P with the aid of which is possible the start of thermocouple or source of current A.

Table 8. Thermoelectromotive force of metals paired with chemically pure platinum with $t = 100°C$ and $t_0 = 0°C$.

(1) Наименование металлов	(2) Обозначение или состав	(3) Температура применения в °C: (5) длительная	(6) кратковременная	(4) Термо-э. д. с. мв
(7) Алюмель	95% Ni+5% (Al+Si+Mn)	1000	1250	—1,02÷1,38
(8) Вольфрам	W	2000	2500	+0,79
(9) Железо (химически чистое)	Fe	600	800	+1,80
(10) Константан	60% Cu+40% Ni	600	800	—3,50
(11) Копель	56% Cu+44% Ni	600	800	—4,00
(12) Медь (химически чистая)	Cu	350	500	+0,76
(13) Платина „Экстра"	Pt	1300	1600	±0,00
(14) Платинородий	90% Pt+10% Rh	1300	1600	+0,64
(15) Платиноиридий	90% Pt+10% Ir	1000	1200	+1,30
(16) Хромель	90% Ni+10% Cr	1000	1250	+2,7÷+3,13

Key: (1). Designation of metals. (2). Designation or composition. (3). Temperature of application/use in °C. (4). Thermoelectromotive force mV. (5). prolonged. (6). short-term. (7). Alumel. (8). Tungsten. (9). Iron (chemically pure). (10). Constantan. (11). Copel. (12). Copper (chemically pure). (13). Platinum "extra". (14). Platinum-rhodium. (15). Platinum-iridium. (16). Chromel.

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During measurement of thermoelectromotive force, the instrument NP by switch P is included in the circuit of thermocouple and by

runner b changes the resistance of circuit until pointer of NP shows zero.

It is obvious that in this position

$$E_{\tau}=IR_{1},$$

where R_1 is a resistance of section ab;

E_{τ} - thermoelectromotive force of thermocouple.

Then by switch P connects source A, and by runner b they again attain zero reading of NP. For this case

$$E_{\text{н}}=IR_{2},$$

where $E_{\text{н}}$ are emf of the normal cell/element A; R_2 is a new resistance of section ab.

Converting obtained equations for E_{τ} and $E_{\text{н}}$, let us find the value thermoelectromotive force of the thermocouple

$$E_{\tau}=E_{\text{н}}\frac{R_{1}}{R_{2}}. \qquad (71)$$

This method provides the high accuracy of the measurement of temperature and is found a use in research practice. At present in research and plant practice are used extensively automatic electronic potentiometers.

Calibration of thermometers and their accuracy/precision.

The calibration of resistance thermometers and thermocouples is produced in water or oil thermostats or at the high temperatures in tubular electric furnaces. Fig. 33, shows thermostat for testing of thermometers in the temperature range from 5 to 300°C.

For the good-quality calibration of thermometers, the thermostat must satisfy a series of the requirements:

1) the temperature field of thermostat must be uniform, with takeoff/run-up it is not more than 0.5°C;

2) for the time of two readings the temperature of liquid must not be changed more than by 0.1°C;

3) liquid level in thermostat during the conduct of calibration must be constant.

During calibration as controls serve the specimen mercury thermometers of the first or second class with scale value 0.1°C in

range from -70 to +102°C and 0.2°C in range from +98 to 302°C.

In readings of mercury thermometer during calibration, it is necessary to correct for the protruding column.

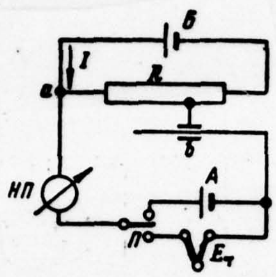

Fig. 32. the schematic diagram of potentiometer. A, B - current sources, $E_т$ - emf of thermocouple, NP - null instrument, b - runner, P - switch.

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Verification/check in the range of minus temperatures produces in the ethyl alcohol, cooled with carbonic acid or Freon.

Setting up for the calibration of thermocouples in tubular electrical furnace is shown in Fig. 34. During calibration as control, is applied the specimen platinumrhodium-platinum thermocouple, which has evidence of the committee of standards, measures and measuring meters.

The temperatures of hot junctions of control and calibrated

thermocouples must be identical, for which them is dipped in nickel block possibly nearer to each other and at identical depth. As shows experiment, the difference in insertion on 5-7 mm is led to a difference in the temperatures of joints in 7-10°C. Thermoelectromotive force of thermocouples measure with laboratory potentiometer.

The information about the highest accuracy of the measurement of temperatures is given in Table 3. The accuracy/precision of the thermometers, used during tests, can be different. for example, the resistance thermometer TUE-48 for the measurement of the temperature of water, oil and surrounding air has a scale from -70 to +150°C with scale value 10°C. An error of measurement at normal temperature does not exceed ±1.5o/o.

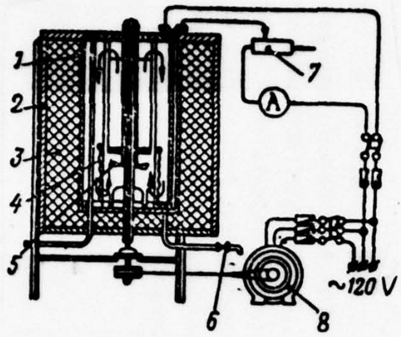

Fig. 33. Thermostat for graduation of thermometers in range from 5 to 300°C. 1 - working vessel, 2 - metal casing, 3 - thermal insulation, 4 - heater, 5 - mixer, 6 - the drain cock, 7 - rheostat, 8 - electric motor.

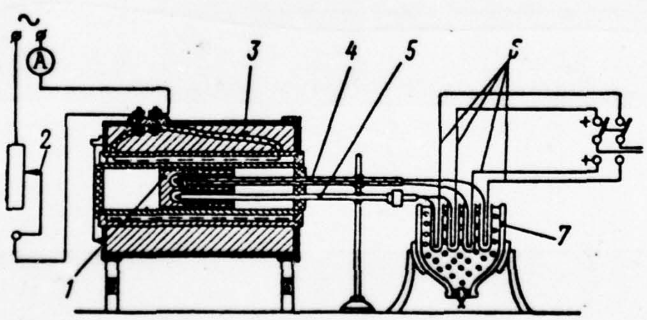

Fig. 34. Tubular electric furnace for the graduation of thermocouples. 1 - metallic block, 2 - rheostat, 3 - electric furnace, 4 - the believed thermocouple, 5 - specimen thermocouple, 6 - coupling (copper) wire/conductors, 7 - thermostat for the cold-soldered joints.

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One ought not to mix the accuracy/precision of thermometers with the accuracy of the measurement of temperature, since in the practice of measurements rarely it is possible to make even the temperature of the sensor with the temperature of the measured medium. The accuracy/precision of thermometer is determined by the accuracy/precision of measurement of temperature of its sensor.

3. Measurement of flows and expenditure/consumptions.

The methods of flow measurement of gases will receive considerable development for the latter of 50 years in connection with aeronautical development and power engineers. In the USSR extensive work on pressure units and temperature gauges in flows are carried out in TsAGI [Central Institute of Aerohydrodynamics im. N. Ye Zhukovskiy (central aerohydrodynamic institute) and TsKTI (central boiler and turbine institute).

Measurement of the temperature of flow.

To measure the temperature of the liquid, which moves at low speed, comparatively is simple. Fig. 35, shows an example of the setting up of the receiver of resistance thermometer for the measurement of the temperature of oil. For an increase in the accuracy of the measurement of the wall of channel, it is necessary to heat-insulate, and receiver to arrange to the towards incident flow.

Precise measurement of the temperature of the fast-moving hot gases is among of complex experimental tasks. At the speed of flow to 50 m/s of the temperature of the quiescent and driving gas, they can be considered identical. During motion at larger gas velocity, is braked in heat receiver and its temperature is raised.

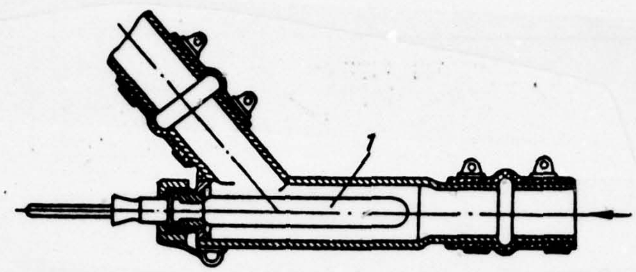

Fig. 35. Setting up of receiver of resistance thermometer in oil-piping layer. 1 - the receiver of thermometer.

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The temperature of the adiabatically stagnant flow (i.e. with absence of heat exchange between the zone of measurement and the surrounding space) is calculated according to the formula

$$T_т^* = T + \frac{Ac^2}{2gc_p}, \qquad (72)$$

where $T_т^*$ is temperature of the adiabatically stagnant flow; T - the temperature of the driving gas; A is the heat equivalent of the mechanical work

$$\left(A = \frac{1}{427}\ ккал/кГм\right);$$

Key: (1). kcal/kg-m.

g - the acceleration of gravity c_p is heat capacity of gas at a constant pressure; c - gas velocity.

In actuality always occurs heat exchange with the surrounding space. To account for heat exchange with the environment and the account of the incompleteness of braking, is introduced the temperature recovery factor of r; then formula (72) of signs the form

$$T^{*}=T+r\frac{Ac^2}{2gc_p}. \qquad (73)$$

Temperature recovery factor r is determined by the expression

$$r=\frac{T^{*}-T}{T^{*}_{\tau}-T}. \qquad (74)$$

In formula (73) it is possible to introduce criterion M:

$$T^{*}=T\left(1+r\frac{k-1}{2}M^2\right). \qquad (75)$$

The theoretical methods of determining value r do not exist and therefore recovery factor is determined experimentally. To the temperature of flow 300°C, value r in essence is determined by the degree of braking flow in the zone of sensing element.

The thermocouple, placed into flow, emits heat to its surrounding walls of channel, which have lower temperature. As a

result of emission/radiation the temperature of thermocouple proves to be less than the temperature of its washing gases.

Let us examine the question concerning the heat exchange of thermocouple with the environment (Fig. 36). let us assume that shield 2 temporarily is absent. Let T_1 be temperature of the walls of tube, T_3 - the temperature of thermocouple, T_τ^* - the temperature of the adiabatically stagnation gas.

A quantity of heat, obtained by thermocouple from gases, is determined by the expression

$$Q_\kappa = \alpha F_3 (T_\tau^* - T_3), \qquad (76)$$

where α is a heat-transfer coefficient from gas to thermocouple; F_3 is a surface area of the thermocouple, receiving heat.

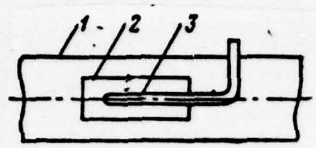

Fig. 36. Schematic of shielded thermocouple. 1 - the wall of channel, 2 - shield, 3 - heat receiver.

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In trimmed/steady-state a quantity of heat, received by thermocouple, equal to the sum radiant heat, scattered by thermocouple to the walls of channel, and the heat, abstract/removed on thermocouple and its housing.

A quantity of radiant heat, loosened by thermocouple, is determined from the formula

$$Q_{л}=\varepsilon C_0 F_3\left[\left(\frac{T_3}{100}\right)^4-\left(\frac{T_1}{100}\right)^4\right], \qquad (77)$$

where ε is given emissivity factor; C_0 is a radiation factor.

Magnitude of given emissivity factor is determined by the expression

$$\varepsilon=\frac{1}{\frac{1}{\varepsilon_3}+\frac{F_3}{F_1}\left(\frac{1}{\varepsilon_1}-1\right)}, \qquad (78)$$

where ε_3 is emissivity factor of thermocouple; ε_1 is a relative radiation factor of canal surface; F_1 is the surface of the wall of channel, which takes part in heat exchange with thermocouple.

Ratio F_3/F_1 is close to zero and therefore

$$Q_{л}=C_0\varepsilon_3F_3\left[\left(\frac{T_3}{100}\right)^4-\left(\frac{T_1}{100}\right)^4\right]. \quad (79)$$

In formulas (77) and (79) C_0 = 4.9 kcal•m²•h•°K⁴, and value depends on material, state of its surface and temperature. For example, for a platinum wire ε_3 = 0.07-0.182 at temperature of 225-1375°C for gland ε_3 = 0.08-0.13 in the range of temperatures 1000-1400°C.

Accepting equality $Q_{к}=Q_{л}$ and disregarding the heat, diverted on thermocouple and its housing, we will obtain

$$T_{т}^{*}-T_3=\frac{C_0\varepsilon_3}{a}\left[\left(\frac{T_3}{100}\right)^4-\left(\frac{T_1}{100}\right)^4\right]. \quad (80)$$

The examination of formula leads to the conclusion that value T_3 that is nearer to $T_{т}^{*}$, than is less ε_3, is more than a and is nearer than t_1 to T_3. Value ε_3 it is impossible to affect in practice.

An increase α can be obtained by an increase in the velocity of the flow about the heat receiver. Last/latter it is possible to achieve by means of the suction of the gases, which surround thermocouple. This method is too complex and usually they resort to other - to the method of shielding, making it possible to draw together the temperatures of thermocouple T_3 and of gases T^*_T.

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If we between the wall of channel 1 and thermocouple 3 place shield 2 (Fig. 36), then its temperature T_3 will be above than the temperature of the cooled wall of channel 1, which will lead to lowering of the losses by thermocouple. Usually the shields of thermocouples design so that they are at the same time and the chambers of braking, i.e., by the chambers in which the gas washes thermocouples at the lowered/reduced velocity.

To evaluate the effect of shielding on the value of the measuring error of temperatures, let us examine an example. Let the thermocouple show temperature T_3 = 1073°K, and the temperature of wall is equal to T_1 = 773°K, α = 200 kcal•h•m²•°K and $C_0\varepsilon_3=4.22$. Then $T^*_T-T_3=204°C$, i.e., measuring error proves to be very large.

Setting of the shield 2 reduces the difference $T^{*}_{\text{т}}-T_{\text{з}}$ to 37°C, i.e., measuring error to decrease 5.5 times. Further decrease in the error can be obtained, after introducing the thermal insulation of the walls of channel and the second shield. During the measurement of the temperature of hot flows (having $T^{*}_{\text{т}}>600°\ \text{K}$) the basic source of errors is the heat exchange.

Let us examine construction and the results of the tests of some thermometer bulbs.

For braking of flow about thermocouple, are applied the chambers of the brakings in which the thermocouple is furnished along flow (horizontal chamber of braking) or perpendicular to the incident flow (the vertically-operated cameras of braking). For the measurement of temperature fields, are applied the combs, which represent by itself several thermocouples, arrange/located in the determined places, in one housing.

Fig. 37, depicts heat receiver with the vertically-operated camera of braking and is shown a change in the temperature recovery factor of r depending on the rate of flow (λ) and of the relationship/ratio of the intake areas and chamber exit ($K=F_{\text{вых}}/F_{\text{вх}}$).

Characteristic for this heat receiver is comparatively small change r in the speed of flow.

Heat receiver for the measurement of the temperature of flow at rates to M - 1.2 is shown in Fig. 38. Thermoelectrodes are insulated with the aid of porcelain tubes. The relationship/ratio of areas K for this heat receiver is equal to 0.2.

are most complicatedly arranged the heat receivers of precise (controls) thermocouples. As an example Fig. 39, gives the construction of control heat receiver. the special feature/peculiarity of this heat receiver is the presence of four shields from which internal is ceramic. The parts of receiver, washed by hot flow, are made from heat-resistant alloy.

Fig. 40, shows the construction of the sensor TGZ-47 for the measurement of the temperature of the stagnation gases.

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Thermocouple is made from nickel-cobalt alloy (NK) and special alumel (SA). The distinctive special feature/peculiarity of thermocouple of the alloys NK and SA lies in the fact that thermoelectromotive force appears with a difference in temperatures

$t>t_0$ 300°C, thanks to which in work with this thermocouple virtually there is no need to correct for the temperature of the cold-soldered joint.

Thermocouple 2 from tube 3, made from heat-resistant steel, is isolate/insulated by ceramic tube 4. The housing of thermocouple establish/install by intake 1 by diameter of 3 mm to towards gas flow; gas at low speed washes thermojunction 2 and emerges through hole 12 by diameter of 0.8 mm. flexible hose 10 protects wire/conductors from breakage. Jumpers they connect to contacts 11.

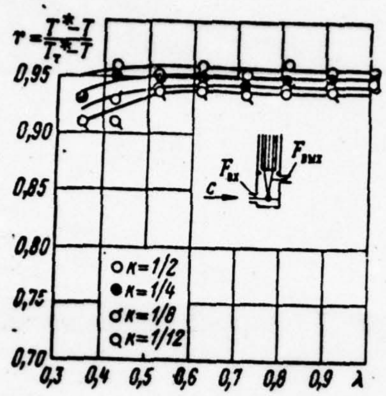

Fig. 37. Characteristic of heat receiver with the vertically-operated camera of braking.

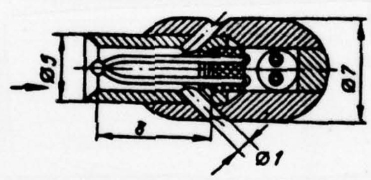

Fig. 38. Thermometer bulb for the measurement of the temperature of flow.

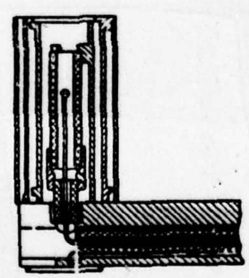

Fig. 39. Construction of control heat receiver.

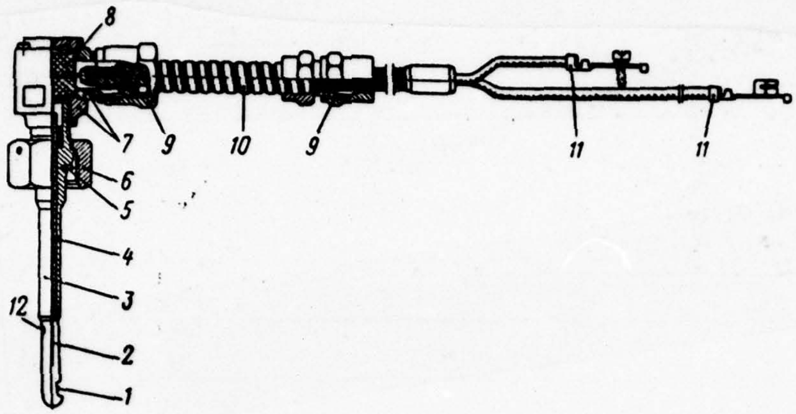

Fig. 40. Construction of the heat receiver TGZ-47. 1 - intake, 2 - thermocouple, 3 - tube, 4 - ceramic tube, 5 - tcmmy, 6 - nut, 7 - housing, 8 - ceramic shoes, 9 - nut, 10 - flexible hose, 11 - contacts, 12 - outlet.

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Independent of construction all heat receivers must pass calibration at special settings up. One Of the possible installation diagrams for the calibration of heat receivers in high-temperature flow is shown in Fig. 41. The calibrated and control of thermocouple alternately (with the aid of coordinate spacer apparatus) they establish/install in one and the same point of flow at the nozzle outlet. Mode/conditions must be kept constant/invariable during 3-5

min. for the exception/elimination of the effect of inertness.

Pressure measurement of flow and its velocity.

During testing of aggregate/units of VRD, usually it is necessary to measure the pressures of the driving liquids; in this case static-pressure probe can be the hole, made in the wall of the tube along which flows the liquid. The total pressure measures with the tube, placed by hole towards to flow.

Let us examine, as it is possible to determine the speed of the subsonic flow of gas with the aid of the combined tube. In the combined tube (Fig. 42) with pitot tube, serves central hole 1, and by static-pressure probe - hole 2. Braking in subsonic flow occurs according to the law of the reversible adiabatic curve and the measured pressure p* is the pressure of isentropic braking.

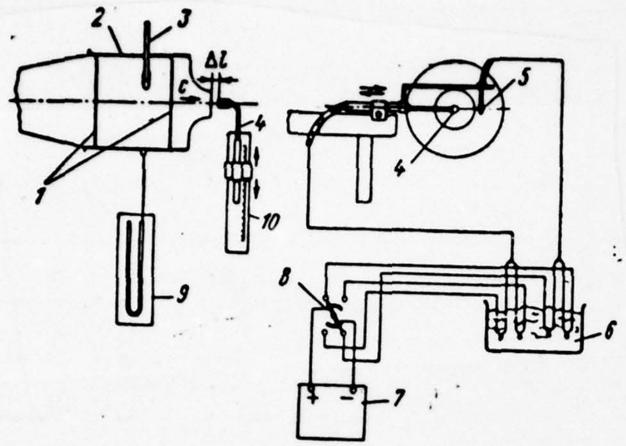

Fig. 41. Installation diagram for the calibration of heat receivers. 1 - sect, 2 - precombustion chamber, 3 - thermocouple for maintaining the mode/conditions, 4 - control thermocouple, 5 - the tested thermocouple, 6 - thermostat, 7 - potentiometer, 8 - switch, 9 - manometer, 10 - coordinate spacer.

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Inlets 2 are furnished at this distance that the received by them pressure would be equal to static pressure p of the incident flow. If are known p and p*, then λ of flow is calculated according to the known formula

$$\lambda=\sqrt{\frac{k+1}{k-1}\left[1-\left(\frac{p}{p^*}\right)^{\frac{k-1}{k}}\right]}, \qquad (81)$$

where k is an adiabatic index, or it is determined with the aid of gas-dynamic tables.

At known temperature of stagnation the critical speed is determined from the expression

$$a_{\kappa p}=\sqrt{\frac{2}{k+1}gkRT^{*}}, \quad (82)$$

and the speed of flow is found by the formula

$$c=\lambda a. \quad (83)$$

The speed of supersonic flow determines also by the combined tube. But in this case the holes of 2 tubes are furnished so that measured by them the pressure p would be equal to the static pressure of flow to the normal shock according to the law of which occurs the braking.

Then λ flow calculate according to curve/graph or to the tables of the gas-dynamic functions:

$$\frac{p}{p^{*}}=\left(\frac{1}{\lambda^{2}}-\frac{k-1}{k+1}\right)\left(1-\frac{k-1}{k+1}\frac{1}{\lambda^{2}}\right)^{\frac{1}{k-1}}, \quad (84)$$

where p - static pressure in flow to shock wave; p* - the total pressure after shock wave.

For the measurement of the total pressure in flow, it is most convenient to utilize the receivers, which possess weak sensitivity

to misalignments. Fig. 43 and 44, shows construction and receiver responses, virtually which does not distort the total pressure during the deviation of velocity vector from the axle/axis of receiver of angle to 25°.

An error of measurement of the total pressure is estimated according to the formula

$$\Delta p = \frac{p_n - p_0}{p_0} \cdot 100, \quad (85)$$

where p_0 is the pressure, measured in the absence of misalignment; p_n is the pressure, by reading instrument.

The airflow or gas, which takes place through the engine, in different cross sections has the different total pressure.

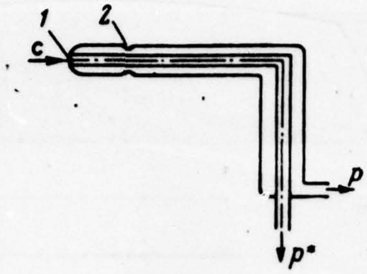

Fig. 42. Schematic of combined tube. 1 - pitot tube, 2 - static-pressure probe.

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Therefore for explaining the picture of the losses of pressure and determination of the speeds in flow, is establish/installed a considerable quantity of pitot tubes.

Fig. 45, shows an example of the setting up of pitot tubes on the edge of stator blade. during the measurement of the total pressure of hot gas (for example, at the nozzle outlet of TRDF [turbojet engine with afterburner]) applies cooled multipoint pitot tubes (comb).

Static pressure of the flow of gas measures both on the

boundary/interface of flow and in its cross sections. the measurement of static pressures on the boundary/interface of flow produces with the aid of the holes, drilled in the walls, which limit flow. As showed experiments, small, to 10° slope/inclination of the axle/axis of hole to wall does not affect the accuracy/precision of readings. The diameter of the drilled holes usually lie/rests within limits 0.3-1.2 mm. The edges of holes must be pure/clean, without projecting edges.

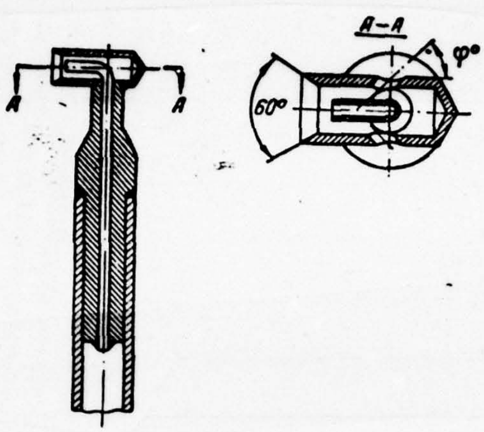

Fig. 43. Pitot tube with duct.

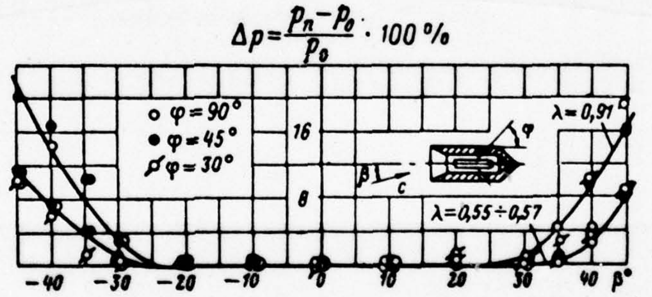

Fig. 44. Receiver responses of the total pressure with duct.

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Static pressure in the cross section of flow measures either

with the already examined combined tubes or special static-pressure probes.

Fig. 46, shows needle receiver for the measurement of static pressure and is given its characteristic on λ, i.e., the dependence λ_{np} (instrument) on λ (flow) with d = 5 mm, δ = 5 mm.

The schematic of the combined receiver for the measurement of complete and static pressures, and also its characteristic are shown in Fig. 47. As can be seen from figure, in this receiver it will be possible to obtain linear characteristic in all range of change λ.

During testing of nozzles, turbines and the compressors when it is undesirable to encumber cross section, temperature and the pressure of flow it is possible to measure with the aid of one rearrangeable coordinate spacer apparatus of receiver.

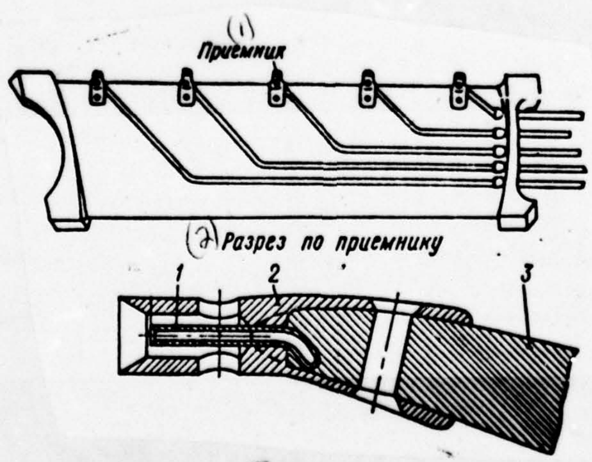

Fig. 45.

Fig. 45. Setting up of pitot tubes on the edge of the blade of guide device. 1 - the tube of the total pressure, 2 - the housing of receiver, 3 - blade.

Key: (1). Receiver. (2). Cut/section on receiver.

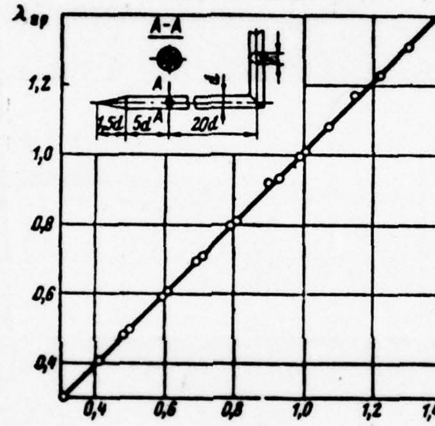

Fig. 46. Needle static-pressure probe.

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Coordinate spacer apparatus - the mechanism, which makes it possible to establish/install receiver to necessary position and to record this position in rectangular or polar coordinates. The drive of coordinate spacer apparatuses can be manual or electrical.

Measurement of flow direction.

Flow direction can be determined by silk filament or the arms, placed into flow. However, this determination of direction inaccurately and is sometimes impossible due to the severe vibration of direction marker.

In the practice of tests, is applied the pneumometric method of determining the direction of speed. Fig. 48, shows the schematic of the pneumometric receiver, which allows a more accurately in comparison with visual methods to determine flow direction in plane, and is given its calibration curve.

On the axis of abscissas, is deposit/postponed value M of flow, while on the axis of ordinates - derived

$$\frac{d}{d\alpha}\left(2\frac{p_1-p_2}{\rho c^2}\right),$$

where p_1 and p_2 are pressures in tubes 1 and 2; ρ is gas density; c is speed; α is a rake angle.

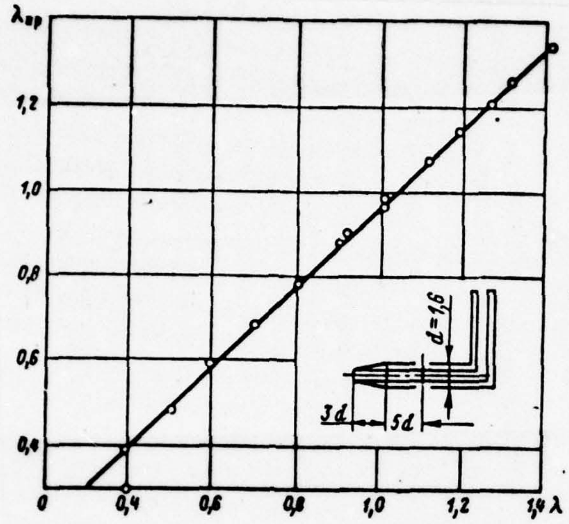

Fig. 47. Characteristics of the combined receiver.

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To use this graph is possible as follows. Let ρ = 0.114 kgf s^2/m^4, c = 170 m/s, M = 0.5; through curve/graph find

$$\frac{d}{d\alpha}\left(2\frac{p_1-p_2}{\rho c^2}\right)=0,0374$$

or

$$d\alpha=\frac{1}{0,0374}d\left(2\frac{p_1-p_2}{\rho c^2}\right).$$

After substituting appropriate values for ρ and c, we will obtain

$$d\alpha=\frac{1}{61,5}d(p_1-p_2);$$

If the difference

$$d(p_1-p_2)=60\ \kappa\Gamma/м^2,$$

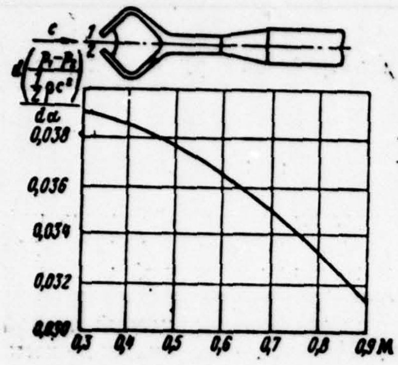
then

$$\Delta\alpha\approx 1°.$$

The given example shows that by pneumometric receiver it is possible to determine flow directions with sufficient accuracy/precision.

Measurement of the fluid flow rate and gases by throttle instruments.

For the measurement of the expenditure/consumption of the stationary fluid flows and gases, are applied throttle instruments - diaphragm and nozzles. Let us examine operating principle and the character of the flow of liquid or gas in throttle device in an example of the diaphragm, shown in Fig. 49.



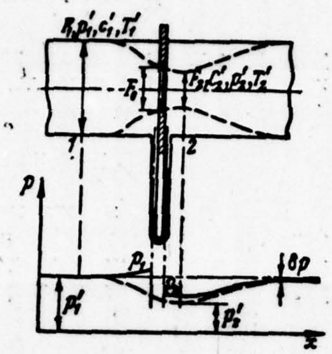


Fig. 48. Fig. 49.

Fig. 48. Pneumometric receiver for measurement of direction of flow and its

Fig. 49. Schematic diagram of throttle instrument (diaphragm) and distribution pressure along the length of channel.

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Let us examine the flow of gas on section 1-2. As is evident, in cross section 1 current gas completely fills tube. With approach to diaphragm and after diaphragm it is possible to separate two fields - the field of jet and the field of circular eddy/vortex; moreover eddy region after diaphragm is considerably more than to diaphragm. As a result of contraction before the diaphragm, the gas is accelerated in axial and radial directions, which is led to the appearance of the

corresponding pressure differentials.

Change in the pressure on the wall of tube by represented solid line, and pressure along the axis of jet - broken. The presence of radial pressure differentials will entail the shift of narrowest jet cross-sectional area F_2 into field behind diaphragm. The phenomenon becomes complicated by the presence of forces of friction on jet boundaries.

Let us examine the simplified theory of throttling device for an incompressible flow. Let on section 1-2 there is no friction, then is correct the equation of D. Bernoulli

$$\frac{p_1'}{\gamma}+\frac{c_1'^2}{2g}=\frac{p_2'}{\gamma}+\frac{c_2'^2}{2g}, \qquad (86)$$

where c'_2 - ideal velocity in the absence of friction (remaining designations are given in Fig. 49).

From the equation it follows that

$$p_1'-p_2'=\frac{\gamma}{2g}(c_2'^2-c_1'^2). \qquad (87)$$

The value of jet cross-sectional area F_2 it is possible to express by F_0:

$$F_2=\mu F_0, \qquad (88)$$

where μ is the coefficient of contraction which is determined experimentally.

After taking into consideration the equation of the continuity

$$F_1c_1' = F_2c_2', \tag{89}$$

from formulas (88) and (89) we will obtain

$$c_1' = c_2'\mu\frac{F_0}{F_1}. \tag{90}$$

After substituting value of c_1' from (90) in (87), we will obtain the value of the ideal velocity

$$c_2' = \frac{1}{\sqrt{1-\mu^2\left(\frac{F_0}{F_1}\right)^2}}\sqrt{2g\frac{p_1'-p_2'}{\gamma}}. \tag{91}$$

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In the actial flow there are losses to friction and nonuniformity of the speed in cross section 2. Furthermore, averaged even in the ideal flow of pressure p_1' and p_2' not at all are measured, but are measured pressures p_1 and p_2 - before and after diaphragm. To account for this, let us introduce correction factor ξ, then the value of the real velocity

$$c_2 = \frac{\xi}{\sqrt{1-\mu^2\left(\frac{F_0}{F_1}\right)^2}}\sqrt{2g\frac{p_1-p_2}{\gamma}}. \tag{92}$$

The weight flow rate of the incompressible gas can be calculated by the formula

$$G=F_2\gamma c_2. \qquad (93)$$

After the substitutions of values F_2 and c_2, we will obtain

$$G=F_0\frac{\mu\xi}{\sqrt{1-\mu^2\left(\frac{F_0}{F_1}\right)^2}}\sqrt{2g\gamma(p_1-p_2)}. \qquad (94)$$

To separately determine values μ and ξ is sufficiently difficult and therefore in practice is introduced the coefficient of the expenditure/consumption

$$\alpha=\frac{\mu\xi}{\sqrt{1-\mu^2\left(\frac{F_0}{F_1}\right)^2}}. \qquad (95)$$

Then expenditure/consumption can be calculated by the formula

$$G=\alpha F_0\sqrt{2g\gamma(p_1-p_2)}. \quad (96)$$

Value γ for gases usually is determined according to equation of state

$$\gamma=\frac{p_1}{RT_1^*}, \quad (97)$$

where p_1 is the static pressure to diaphragm;

T^*_1 - the temperature of stagnation of the flow before the diaphragm.

Temperature is measured at a distance, equal to 10-20 diameters of tube in order to eliminate the effect of heat receiver on flow in throttle instrument and on its readings. Thus, the specific gravity/weight of gas γ in this formula - value is conditional.

During the determination of the gas flow to account for compressibility, is corrected for the expansion of the measured medium ε and formula for the calculation of the expenditure/consumption of gas of signs the form

$$G=\alpha\varepsilon F_0\sqrt{2g\gamma(p_1-p_2)}. \quad (98)$$

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For gases and vapors $\varepsilon<1$, for liquids $\varepsilon=1$.

Device and the size/dimensions of throttle instruments are standardized. The method of the calculation of throttle devices is given in "rules 27-54 on application/use and the verification/check of flow meters with normal diaphragms, nozzles and Venturi tubes".

Fig. 50, shows standard diaphragm and nozzle and the constructions of flanged devices for the selection of pressures. In the upper part of the cut/sections, are given disk, while in lower - chamber flanged devices.

Chamber devices are more complex and more expensive, for the measurement of pressures in the annular grooves, it gives more accurate results and makes it possible to reduce the length of entire section of measuring device. Diaphragms are simpler than nozzles and better are investigated, but in comparison with nozzles they possess high hydraulic resistance.

Throttle instruments are applied without calibration, if D $\geqslant$ 50 mm and d/D lie/rests within limits of 0.2-0.85 for diaphragms even 0.2-0.8 - for nozzles.

For the manufacture of diaphragms and nozzles, utilize corrode the materials: stainless steel, brass, bronze or common steel with protective coating.

Operating conditions of diaphragms and nozzles are extremely diverse and therefore during the calculation of the gas flow according to readings of throttle instruments, it is necessary to introduce a series of corrections.

The coefficient of expenditure/consumption can be represented in the form of the product

$$\alpha=\alpha_0 K_\mu K_ш K_к K_t, \qquad (99)$$

where α_0 is an initial coefficient of expenditure/consumption;

K_μ — поправочный множитель на вязкость; (1)
$K_ш$ — " " на шероховатость; (2)
$K_к$ — " " на неостроту кромки; (3)
K_t — " " на тепловое расширение диафрагмы (4)
(5) (сопла).

Key: (1). correction factor to ductility/toughness/viscosity. (2). to roughness. (3). to the nonsharpness of edge. (4). for the thermal expansion of diaphragm. (5). (nozzle).

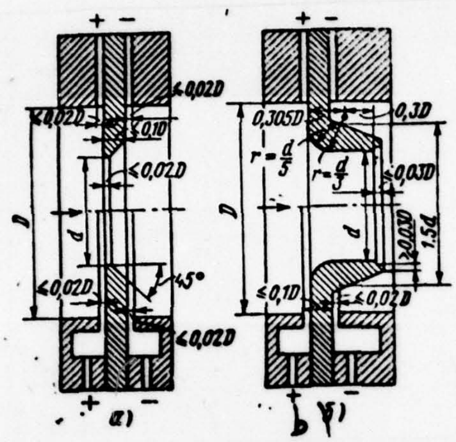

Fig. 50. Standard diaphragm (a) and nozzle (b).

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The values of correction factors depend on the parameters of process and construction of the throttle instrument:

$$K_{\mu}=f\left(\frac{d}{D},\ \mathrm{Re}=\frac{cD}{\nu}\right),$$

where ν — a kinematic viscosity coefficient of gas into m^2/s;

$$K_{ш}=\varphi\left(D,\frac{d}{D}\right);$$
$$K_{к}=\psi\left(D,\frac{d}{D}\right);$$
$$K_{t}=\eta(t).$$

For diaphragms and nozzles, there are curves, on which it is possible to find values of correction factors. Thus, for instance, for a diaphragm at the diameter of tube D = 100 mm and d/D = 0.5 value $K_{\mu} = 1.015$ (at Re = 10,000), value $K_{m} = 1.008$ and $K_{k} = 1.008$.

Under the same conditions for nozzles $K_{\mu} = 0.965$ and $K_{m} = 1.000$ value K_{k} is always equal to one.

Value K_{t} depends on material of diaphragm (nozzle) and of temperature. Values of correction factor K_{t} for brass are given in Table 9.

When selecting diaphragm or nozzles, one must take into account the permissible magnitude of losses of pressure, the possibility of manufacture and the cost/value of instrument, operating condition. It is important to also observe the rules of the setting up of throttle

instruments. During horizontal or inclined instrumentation, it is necessary to provide the holes: during the measurement of fluid flow rate - for an issue from the chambers of air and vapors, during the measurement of the gas flow - for the descent of condensate.

In front and from behind instrument must be rectilinear damping sections. The lengths of damping sections up to instrument l_1 and after instrument l_2 depend on the presence in the flow of the perturbation devices and plenum chamber, and also from ratio d/D. For example, if before and after instrument stand tap/cranes, then with d/D = 0.5 for a diaphragm without the chamber is required $l_1/D=47$, $l_2/D=5$ also, for diaphragm with the chamber $l_1/D=12$, $l_2/D=5$. This example it shows, as is great the role of the chamber for the damping of pressure in the zone of measurement.

Table 9. Values K_t for diaphragms it puffs from brass.

t° C	20	100	200	300	400	500
K_t	1,000	1,003	1,007	1,011	1,015	1,019

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For the measurement of the large fuel consumptions at the experimental stations there found limited application the third type of throttle instrument is a Venturi tube (Fig. 51). Essential advantage of Venturi tube in comparison with nozzles, and in particular with diaphragms, low resistance. During the measurement of the fuel consumption, it is completely acceptable according to size/dimensions and it is reliable.

Volumetric flow meters.

For the measurement of volumetric fluid flow rate, apply fuel meters and rotational flow meters (latter they can be used also for the measurement of the expenditure/consumption of gases).

Fig. 52, shows fuel meter with photocells for the time mark of the passage of the fuel level of control scratches. Fuel meter is establish/installed in fuel system.

Service tank 2 is connected by sleeve with holes 1 with the housing of 15 ball cock. To central tube 3, are planted disks 13, which isolate measured capacitance/capacities. Window 4 serves for visual observation of the passage of the fuel/propellant through measured scratches. Adapter 5 with branch 6 for the pass of fuel/propellant connects service tank 2 with compensation tank 10.

In compensation tank 10, is window 7 for observation of liquid level during the control of counterpressure. Overflow pipe 9 serves for the pass of air from compensation tank 10 into service tank 2. Air pressure in compensation tank 10 is regulated by the tap/crane, establish/installed in cap/cover 8. Branch 6 and case of cock 20 are connected with the main line, which feeds fuel/propellant to fuel meter, and output branch 17 is with the main line, which feeds fuel/propellant to engine. photocells 12 are placed in column and "observe" the passage of fuel/propellant of the disks of 13 measured capacitance/capacities.

During operation of engine, the float in housing 15 stands in upper position and its lever rests in plate 16, as shown in figure. If lever 18 of cam 21 stands in vertical position, then cam holds valve 22 opened. The spring of cam in this case has minimum length.

Fuel/propellant is passed through the valve into the housing of 15 ball cock and further into engine.

The tube, which supplies fuel/propellant to compensating tank through branch 6, and service tank 2 is filled by fuel/propellant, and the large part of compensation tank 10 - by air. The fuel level in compensation tank can be regulated, changing air pressure by the tap/crane, establish/installed on cap/cover 8.

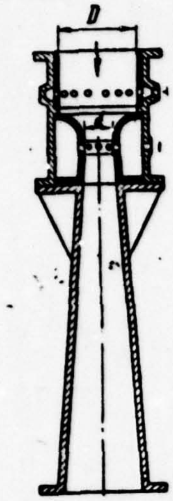

Fig. 51. Venturi tube.

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For the measurement of the fuel consumption the cylinder of cam 21 they turn by hand in the position, shown on figure. In this case, valve 22 is closed, and the lever of 18 cam 21 goes for the cam of 19 float. Since valve is closed, fuel/propellant begins to be expend/consumed from service tank 2, and the place of fuel/propellant from compensation tank 10 enters air. In the space being freed in tank 10 through branch 6 of the main line, enters the fuel/propellant. Tube 9 does not make it possible for this fuel/propellant to be recasted into service tank 2 until fuel/propellant in tank 10 is achieved the upper edge of tube 9. When fuel level is achieved float chamber, float lowers and its cam 19, being turned, it free/releases lever 18.

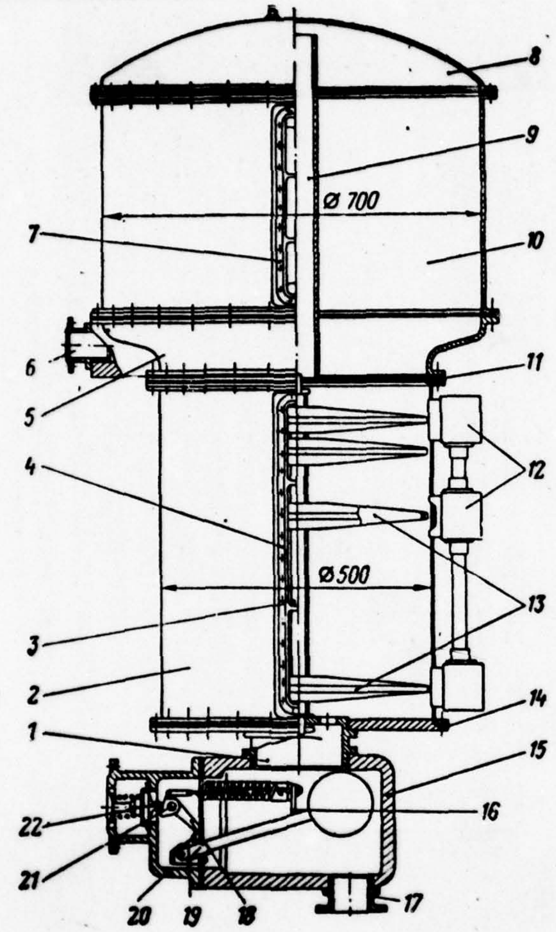

Fig. 52. Fuel meter. 1 - sleeve, 2 - service tank, 3 - central tube, 4 - window, 5 - adapter, 6 - branch, 7 - the window of compensation tank, 8 - cap/cover, 9 - recasting tube, 10 - compensation tank, 11 - upper flange, 12 - photocells, 13 - disks, 14. lower flange, 15 - the housing of the ball cock, 16 - plate-detent, 17 - output branch, 18 - lever, 19 - the cam of float, 20 - case of cock, 21 - the open/disclosing cam, 22 - intake valve.

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Spring turns cam 21 and it automatically open/discloses valve 22.

Photocells are included in the system of the automatic measurement of the fuel consumption which is given in Fig. 53. When fuel level is passed through "observed" by photocell field, it gives the signal through the amplifier 4 and thyratron relays 5 for the "launching/starting" of chronograph 6 and of the spark illuminator of 8 camera. At the torque/moment of the overshoot of spark, are photographed clock readings 13 and of the revolution counter of 12 shafts of engine.

Fig. 54, gives the schematic of rotary-disk meter with the oval gears which, being located friend with other, they are rotated under the action of the pressure differentials of liquid at entrance and exit from instrument.

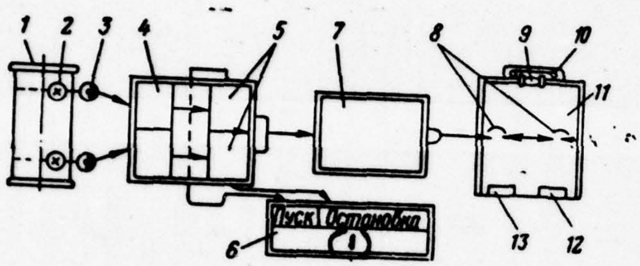

Fig. 53. Diagram of automatic system of measurement of fuel consumption. 1 - fuel meter, 2 - the bulb of illumination, 3 - photocells, 4 - amplifier, 5 - thyratron relay, 6 - chronograph, 7 - high-voltage generator, 8 - spark illuminator, 9 - objective, 10 - photographic film, 11 - camera, 12 - revolution counter, 13 - stopwatch.

Key: (1). Launching/starting is stop.

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The volumetric flow rate of fuel/propellant is determined according to counter mechanism or calculate according to the formula

$$V=\eta\frac{n}{60}4V_1, \qquad (100)$$

where V_1 is the volume, seized by gear;

η — the charge/weight ratio, which considers clearance losses;

n - the number of revolutions of cylinder per minute.

Standard counters of such type are applicable according to their dimensions and weight only for operation under ground conditions.

Fig. 55, gives the schematic of rotational gas counter. Blade/vanes (the "eights"), establish/installed in the housing of counter, are profiled so that they clear neither housing nor each other; rotation from one blade/vane to anotner it is transferred by gears, which are located beyond the limits of working cavity. Blade/vanes are rotated under the action of pressure differential between entrance and exit; this jump/drop on normally working counter does not exceed 30 mm water column.

rotary-disks meter are reliable and are sufficiently precise, but they do not possess high productivity. Flow meters of this type can also be applied for the measurement of nonstationary expenditure/consumptions.

Rotameters.

The device of rotameter is shown in Fig. 56. In conical tube 1 with the scale in the ascending propellant stream, is located float 2. During the motion of liquid, the float is establish/installed on such height/altitude where its excess weight is equal to the lift force, which depends on the speed of the flow about the float.

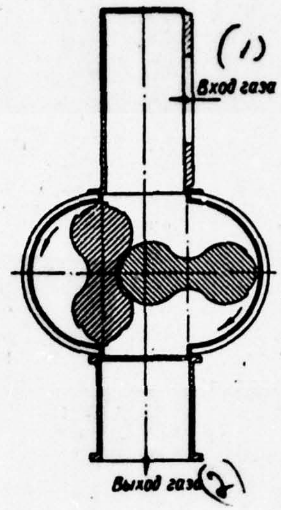

Fig. 55.

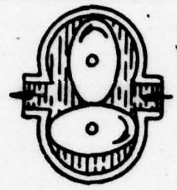

Fig 54.

Fig. 54. Schematic of rotary-disk meter.

Fig. 55. Schematic of rotational gas counter.

Key: (1). Entry of gas. (2). Output/yield of gas.

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Excess weight is equal to a difference in the weight of float in void and in the weight of liquid in the volume of float.

let us write the equation of the equilibrium of float in fluid flow

$$G_{\text{п}} = V_{\text{п}}(\gamma_{\text{п}} - \gamma_{\text{т}}) = c_x \frac{\gamma_{\text{т}}}{g} f_{\text{п}} c_{\text{т}}^2, \qquad (101)$$

where $G_{\text{п}}$— the excess weight of float;

$V_п$ — the volume of float;

$\gamma_п$ — the specific gravity/weight of float;

$\gamma_т$ — specific gravity of fuel (it is measured by hydrometer);

c_x — the drag coefficient of float, depending on the ductility/toughness/viscosity of fuel/propellant, the rate of flow of fuel/propellant and form of float, and also from the position of float;

$f_п$ — the area of the maximum cross section of float;

$c_т$ — the rate of flow of the liquid before the float.

After simple conversion we will obtain expression for determining the volumetric flow rate of the fuel/propellant

$$Q=f_p\sqrt{\frac{V_п g}{f_п c_x}\,\frac{\gamma_п-\gamma_т}{\gamma_т}}, \qquad (102)$$

where f_p — is a cross-sectional area of tube.

The rotameters are compact, are simple and show the instantaneous value of the volumetric flow rate of fuel/propellant. They are suitable also for the measurement of the gas flow. However, readings of rotameters depend on the specific gravity/weight of liquid, its ductility/toughness/viscosity and on temperature. This considerably decreases the accuracy of measurements.

Gravimetric method of the measurement of the fuel consumption.

Setting up for the measurement of the fuel consumption by the gravimetric method (Fig. 57) consists of weights, 3, service tank 7, compensation tank 5, flexible hoses 6 and 8, compensating tube 2, three-way cock 9 and of air cock 4.

For filling of setting up tap/crane 9 is placed in position of a, tap/crane 4 - they close, and tap/crane 1 - is open/disclosed. Fuel/propellant from main line fills a tank 7 and the part of compensation tank 5. Tap/crane 4 serves for pressure adjustment of air in compensation tank 5 and torque/moment of the beginning of the overflow of fuel/propellant into tank 7.

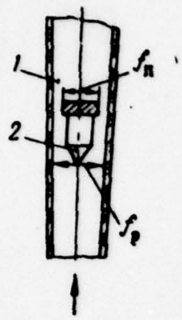

Fig. 56. Schematic of rotameter. 1 - conical tube, 2 - float.

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In order to measure the fuel consumption, three-way cock 9 is placed in position of 6 and are measured time and fuel load, spent from tank 7. With expenditure tank 5 is charged by the fuel/propellant through compensating tube 2; when the fuel level in tank 5 is equaled with the upper edge of overflow pipe, begins the overflow of fuel/propellant into tank 7 and measurement it becomes impossible.

Weights must be arrow type and sufficiently sensitive. The sensitivity of balance in setting up system can be tested, controlling their reaction for low loading with the

expenditure/consumptions, which correspond to three basic engine power ratings. The gravimetric method of measurement more complex, than volumetric, but does not require the measurement of the specific gravity/weight of liquid (fuel/propellant, oils).

Accuracy of the measurements of flows and expenditure/consumptions.

The data on the highest accuracy of the measurement of the temperature of fixed media and the accuracy/precision of measurement by working thermometers are given in Table 10 and 11.

Errors during the measurement of the temperature of the fast-moving gases appear from different reasons.

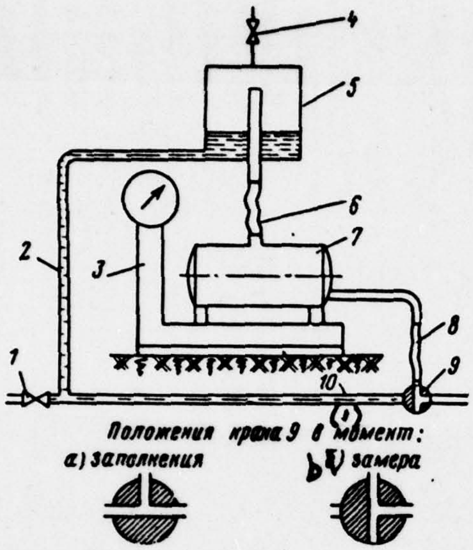

Fig. 57. Installation diagram for weight measurement of fuel consumption. 1 - main tap/crane, 2 - compensating tube, 3 - weights, 4 - the air cock, 5 - compensation tank, 6, 8 - flexible hoses, 7 - service tank, 9 - three-way cock, 10 - fuel pipe.

Key: (1). Positions of tap/crane 9 at the torque/moment: a) filling. b) measurement.

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During the rational selection of form and size/dimensions of the chamber of braking, which plays simultaneously and the role of single

shield, an error of measurement by the thermocouples of flow to 900°C can be considered equal to ±1.0-1.5o/o. This error is obtained upon the setting of heat receiver into the uncooled tube and during the measurement of thermo- emf by a potentiometer of the type PP.

Table 10. The metrological (is highest) accuracy of the measurement of the temperature of bodies.

Температура стоградусной шкалы °С (1)	Погрешность измерения °С (2)	Наименование прибора (3)
—183	±0,005	Термометр сопротивления эталонный (4)
0	±0,003	То же (5)
100	±0,005	То же (5)
444,6	±0,012	То же (5)
500	±0,020	Термометр сопротивления образцовый (6)
600	±0,100	Термопара платинородий-платиновая, эталонная (7)
1300	±0,200	То же (5)
2000	±4,0	Оптический пирометр эталонный (8)
3000	±5,5	То же (5)

Key: (1). Temperature of centigrade scale °C. (2). Error of measurement °C. (3). Designation of instrument. (4). Resistance thermometer is standard. (5). The same. (6). resistance thermometer is specimen. (7). Thermocouple platinum-rhodium-platinum, standard. (8). The optical pyrometer is standard.

Table 11. Accuracy/precision of the measurement of the temperature of media by working thermometers.

Температура стоградусной шкалы °С (1)	Погрешность измерения % (2)		Наименование приборов (3)
—183÷600	±1,0÷1,5 от верхнего предела шкалы (4)		Термометр сопротивления (5)
600÷1300	±0,3		Термопара платинородий-платиновая (6)
600÷1300	±1,0	от измеряемой температуры (7)	Термопара хромель-алюмелевая (8)
(9) до 1400	1		Оптический пирометр (10)
(9) до 2000	1		То же (11)

Key: (1). Temperature of centigrade scale °C. (2). Error of measurement o/o. (3). Designation of instruments. (4). from the upper limit of the scale. (5). Resistance thermometer. (6). thermocouple platinum-rhodium-platinum. (7). from the measured temperature. (8). Thermocouple chromel-alumel. (9). to. (10). The optical pyrometer. (11). The same.

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The accuracy/precision of the measurement of the temperature of flows by series electrical resistance thermometers is characterized by following data.

The standardized electrical resistance thermometer TUE-48 for the measurement of the temperature of oil, water and air in the range from -70 to + 150°C gives error ± 4.3o/o. An error in the thermocouple TGZ-47 in operating range 400-900°C, according to the data of plant calibration is equal to 8-20°C. Upon setting by engine, this error grow/rises due to the intensive heat exchange.

During the measurement of the pressure of driving gas to errors in the manometers, are added errors in pressure units. Errors in pitot tubes in subsonic and supersonic flows are very small.

The measurement of static pressures, as a rule, it is less accurately. Static-pressure probes give error usually not more than 1.5o/o.

The accuracy/precision of the determination λ of flow is determined by the accuracy of the measurement of pressures. For needle receivers the average quadratic error in the calibrations, determined by the deviations of experimental points from linear characteristic, in the range λ = 0.3-1.4 does not exceed 0.6o/o.

During the execution of throttle instruments in precise conformity with rules 27-54, can be provided the accuracy of the measurement of expenditure/consumptions with an error in order ± 1o/o. An error in the throttle instruments sharply grow/rises in the case of the measurement of the expenditures of pulsative flows and can be determined dozen percent.

The accuracy of the measurement of the fuel consumptions with the aid of fuel meters depends on the accuracy/precision of calibration, determination of specific gravity/weight and measurement of time. Time is measured with the aid of common stopwatch with error of approximately 0.3 s., and experimenter's error with the reading of the passage of fuel level is obtained about 0.2-0.3 s.

With the duration of measurement 30 s. an error in the evaluation of the consumption of the fuel/propellant of order 1.5o/o.

If we increase the volume of the used bulb/flasks, and to design them for 60 s., but as stopwatches to use chronoscopes with the half-period of the oscillation/vibration of balance 0.01-0.02 s., then error is obtained order ±0.5o/o. Accuracy/precision can be raised, after using the automatic recording of the time of the fuel consumption from measured volume.

An error in the volumetric counters with oval gears of the type SVSh 5-16/40 is equal to ±0.5o/o of the measured value. An error in the rotameters is equal approximately ±2.5o/o.

The accuracy/precision of the gravimetric method of the measurement of the fuel consumption is determined by the accuracy/precision of weights and recordings of the time of fuel consumption. The accuracy of the measurement of weight is obtained order ±0.2o/o. If we for recording of time use chronoscope and photocell, then during the measurement of expenditure/consumption during 30 s. (error of measurement of the time of order 0.1 s.) we will obtain a common/general/total error in order ±0.5o/o.

For an increase in the accuracy of measurements with this equipment, it is possible to recommend the method of repeated measurements. The evaluation of result is obtained by the averaging of findings.

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4. Gas analysis.

The gas analysis of combustion products is carried out only during the special studies of the combustion chambers. In practice won acceptance of two types of gas analyzers - chemical and electrical. Electrical gas analyzers are less precise.

The simplest includes the gas analyzer chemical portable GKhPZ, determining percentage of CO, CO_2, O_2. The action of gas analyzer is based on the ability of solutions to absorb gases and the measurement of the volume of the gas, which remained that which was nonabsorbed.

On Fig. 58, is represented the diagram of GKhPZ. The test sections of GKhPZ are made from glass. Gas is gathered into burette 8, which has volume 100 ml; with the aid of this same burette is measured the volume of gas after absorption. The lower part of the burette, utilized with the reading of the absorbed gases, it makes it possible to measure the volume of gas more accurately than upper

(since it has the smaller diameter). Burette is submerged in vessel with water, which decreases the temperature variations in the process of gas analysis.

Absorbing vessels 7 (U-shaped form) are filled by glass tubes and absorbing solutions; tubes increase the absorbing surface and accelerate thus the course of analysis.

Distributive comb 6 connects vessels 7 and burette 8 with gas filter 2 or pear 9 (depending on the position of three-way cock 5).

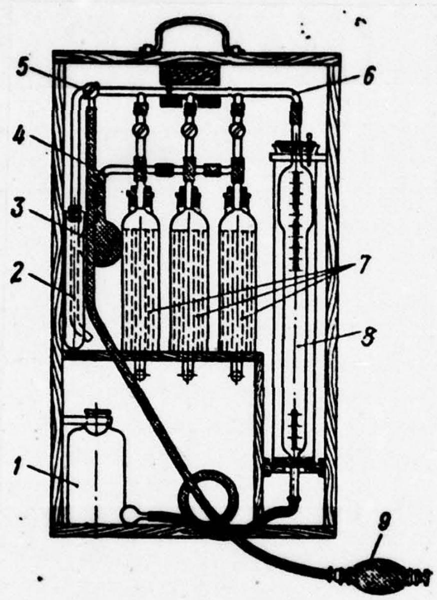

Fig. 58. Schematic of gas analyzer. 1 - equalizing vessel, 2 - filter, 3 - rubber follicle, 4 - connecting tube, 5 - three-way cock, 6 - distributive comb, 7 - absorbing vessels, 8 - burette, 9 - pear.

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In gas filter 2, which is the U-shaped tube, well-packed by glass wool, are retarded the solid particles, which are found in the gas, undertaken for analysis. Pear 9 serves for the suction of the gas

through filter 2 and the flushing of distributive comb as 6 analyzed gas, which enters from burette 8. Tube 4 connects absorbing vessels 7 with rubber follicle 3, which insulates system from air.

Gas analysis is divide/marked off during two operations - training/preparation and strictly analysis.

During training/preparation filter 2 they connect by the cooled copper tube with the separator of gas; by tap/crane 5 main line and filter 2 they connect with pear 9, by which they suck gas. Burette 8 and comb 6 wash in gas with the aid of equalizing vessel 1 and pear 9; lowering vessel 1 with lock liquid, gas they take away into burette 8. Then is removed the mixture of gas and air by the lift of vessel 1 and by pear 9.

After flushing the system is filled with the pure analyzed gas. By tap/crane 5 measuring system is insulated from filter 2 and pear 9. Pressure in system must be equal external (i.e. the level of lock liquid in burette 8 is identical to the level in vessel 1).

For analysis is open/disclosed the tap/crane of first absorbing vessel 7 and by the lift of equalizing vessel 1, several times they distill gas from burette into absorbing vessel; when vessel 7 is filled with gas, liquid from it departs to its another part (vessel

of the U-shaped form), and air - on tube 4 to follicle 3.

When absorption in the first absorbing vessel ends, the tap/crane of this vessel is closed and determine the volume of the remaining gas. Then operation is repeated with other vessels. With the measurement of the volume of the nonabsorbed gas the levels in vessel 1 and burette 8, must be combined.

As lock liquid in equalizing vessel serves salt water (sometimes - mercury). For absorption CO_2, is applied the solution 100 g of the potassium hydroxide (KON) in 200 g of the distilled water; for absorption O_2 - solution 80 g KON and 30 g of pyrogallol in 100 g of the distilled water; for absorption CO - solution 250 g of ammonium chloride (NH_4Cl) and of 200 g of cuprous chloride in 750 g of the distilled water. Nonabsorbed there remains only nitrogen.

Accuracy/precision of the examined method of determining the composition of gas approximately 0.1-0.2o/o.

5. Measurement of the thrust force and torque/moment.

The measurement of thrust/rod is a necessary cell/element of the

tests of all jet engines, including turboprop, during testing of which, furthermore, it is necessary to measure torque.

The measurement of thrust/rod or torque/moment is reduced to force measurement, for determining which we apply: lever/crank dynamometers, dynamometers, spring dynamometers with electric sensors, etc.

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Lever/crank dynamometers.

To Fig. 59, is shown the schematic of lever/crank dynamometer with the optical transmission system of readings and increase in the scale.

The thrust force of engine (or the force, which affects from torque/moment) is transferred by transfer table 1, on which is establish/installed the engine, through branching/fork 2, intermediate thrust/rod 3, horizontal L-shaped lever 4 and thrust/rod to weights 5 (effort/force must dilate/extend thrust/rod 5). Thrust force is absorbed by vertical L-shaped lever 16 and with the aid of

intermediate thrust/rod 17 is transferred to the receiving lever dynamometer 18.

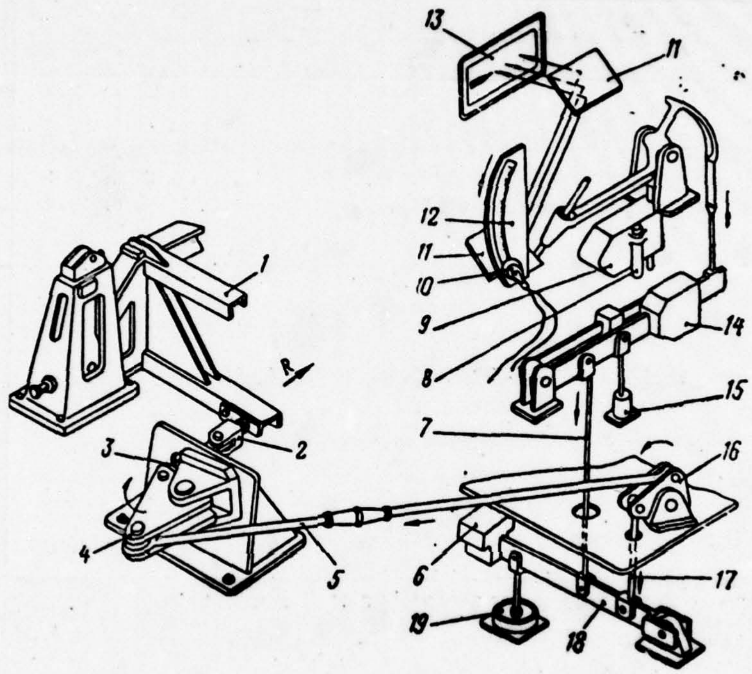

Fig. 59. Schematic of lever/crank dynamometer with the optical transmission system of readings and increase in the scale. 1 - mobile platen, 2 - the transmitting branching/fork, 3 - intermediate thrust/rod, 4 - horizontal L-shaped lever, 5 - thrust/rod to weights, 6 - load for the initial load of system, 7 - vertical thrust/rod, 8 - the screw/propeller of fine adjustment, 9 - the counterweight, 10 - optical system (tube): 11 - mirror, 12 - the scale of dynamometer, 13 - the shield of dynamometer, 14 - the load of the installation of

scale value, 15 - damper, 16 - vertical L-shaped lever, 17 - intermediate thrust/rod, 18 - receiving lever of dynamometer, 19 - damper.

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To lever 18, is connected load 6 for the initial load of system and oil damper 19 for the vibration damping of system.

Further effort/force is transferred through thrust/rod 7 to balance-weight lever 14, employed for setting of scale value, and damper 15, which damps oscillation/vibration and by that smoothing load changes.

Then the effort/force through the rod and the steel strip, which rests on airfoil/profile, is transferred tc pendulum with load 9, which balances the measured force. During a change in the effort/force, scale 12 is moved and its readings with the aid of bulb 10 and the system of mirrors 11 are transferred to the shield of dynamometer 13.

The examined dynamometer is very simple and reliable in operation. However, vibrations can lead mechanical system in

resonance oscillations, which sharply decreases the accuracy of measurements. Is removed this shortcoming by the adjustment of the system of dynamometer.

Furthermore, in the system of dynamometer there are many hinge joints in which are applied the antifriction bearings. During operation bearings must be shielded from contamination and water, since their blockage decreases the accuracy/precision of dynamometer. To the accuracy/precision of measurement, also has effect the appearance of dents on the path/tracks of bearings. Therefore in similar type, measuring systems they try hinge joints to fulfill in the form of prisms or flexible strips.

Liquid dynamometers (dynamometers).

In the practice of laboratories and experimental stations, find a use non-flow and flowing liquid dynamometers (dynamometers).

Non-flow (i.e. without the constant duct of liquid) dynamometers with the rotating cylinder or the piston, given into action by special electric motor, are complex, but they possess that which was increased, in comparison with other non-flow dynamometers by

accuracy/precision. Dynamometers with separating diaphragm are simple on device, but for obtaining precise measurements, they require absolute airtightness, the absence in the system of air locks, insensitivity of system to temperature variations.

To Fig. 60, is shown non-flow dynamometer with separating diaphragm. Liquid dynamometer (dynamometer) consists of piston 3, the housing of 1 and separating diaphragm 4. Support ring 2 limits piston stroke, elastic diaphragm/membranes 5 direct its motion. Branch 6 serves for the measurement of oil pressure.

Liquid dynamometer works as follows. The measured force is applied normal to piston and is balanced by the counteraction of membranes 5, diaphragm 4 and of the pressure of working fluid.

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As working fluid are applied transformer oil, glycerin, mixture of glycerin with alcohol and other liquids, which retain low ductility/toughness/viscosity at low ambient temperature. The pressure of working fluid is measured by a precise manometer, calibrated on the measured effort/force. The effect of the elasticity of diaphragm/membrane and diaphragm is considered by calibration. Piston stroke must be small - order 0.05-0.10 mm. When, in the

system, air sacks and temperature effects are present, on the volume of liquid, the accuracy of measurements is depressed. These shortcomings to a considerable degree is deprived flowing dynamometer.

The schematic of flowing dynamometer with the regulation of intake and output area is shown to Fig. 6.1. From oil tank 1 through filter oil, it enters oil pump 2 in which there is a reduction valve, which supports constant pressure in intake main line 3, moreover is knowingly higher, than it can be required in force gauge.

Oil under high pressure (for example, 50 kgf/cm²) is fed to intake chamber of 4 cylinders of dynamometer 5. In intake chamber 4, is spring 6 and intake shutoff valve 7. On one stock/rod with intake valve 7 sits out-gate 8 with spring 9. In piston 10, is a hole for the jettisoning of oil through main line 11 in oil tank.

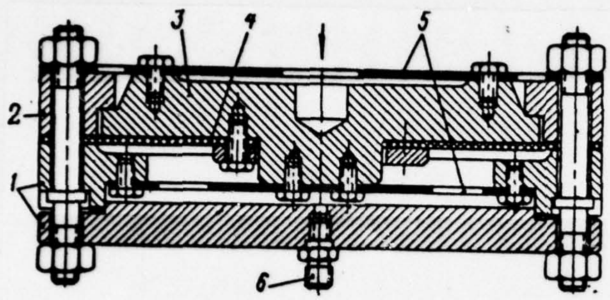

Fig. 60.

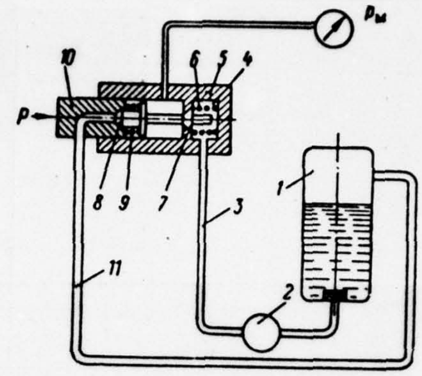

Fig. 61.

Fig. 60. Non-flow dynamometer with separating diaphragm. 1 - housing, 2 - thrust ring, 3 - piston, 4 - diaphragm, 5 - directing diaphragm/membranes, 6 - branch.

Fig. 61. Schematic of piston dynamometer with the adjustable intake area and oil outlet. 1 - oil tank, 2 - oil pump, 3 - intake main line, 4 - intake chamber, 5 - the cylinder of dynamometer, 6 - the spring of intake valve, 7 - intake valve, 8 - out-gate, 9 - the spring of out-gate, 10 - piston, 11 - output main line.

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Under the action of the measured force P, piston 10 is misaligned and valve 7 is open/disclosed. Oil enters the cavity of piston until

force P is balanced by oil pressure and by the force, which effects in the system of valves.

If force P decreases, then piston will go away to the left, valve 7 will discontinue the access of oil, and valve 8 will open outlet and oil pressure in the cavity of piston will fall. Oil pressure in the cavity of the piston is measured with high accuracy/precision - order ± 0.1o/o.

For the measurement of oil pressure in the cavity of piston, can be used hydro-receiver 1 (Fig. 62) with precise pendulum weights of 2. Oil from the piston cavity is fed to the hydro-receiver of dynamometer; the force, which effects on the piston of hydro-receiver, is balanced by precise pendulum weights. Entire measuring system is calibrated with the aid of precise loads.

To Fig. 63, is given the cut/section of the membrane/diaphragm flowing dynamometer, working on the same principle, as flowing piston dynamometer. Since the measurement of effort/force in flowing dynamometer is carried out in the torque/moment of equilibrium, the accuracy/precision of its readings do not in practice affect air bubbles and a change in the temperature conditions. The pistons of dynamometers accomplish very low displacement/movements. Decrease in piston stroke of dynamometers contributes to an increase in the

accuracy of measurements.

Considerable interest for the tests technique of turboprop engines are of torque meters (IKM). IKM is component part of TVD [turboprop engine] and makes it possible to measure the torsional moment both on the stand of experimental station and in flight.

Are most common hydraulic IKM. One of the possible schematics of hydraulic IKM is represented on Fig. 64. During the transfer of the power of the engine through planetary gear to output shaft 5, appears reactionary torque on fixed gear 2; torque/moment from wheel (force P_0) is transferred to the housing of the reducer through the ball/spheres, which convert the rotary motion of wheel into forward/progressive piston stroke 3 (under the effect of force T). Piston stroke 3 will be discontinued at the torque/moment when the force, which affects the piston, is balanced by the oil pressure, which grows due to contraction of area of outlet. The value of torque is judged by pressure of oil.

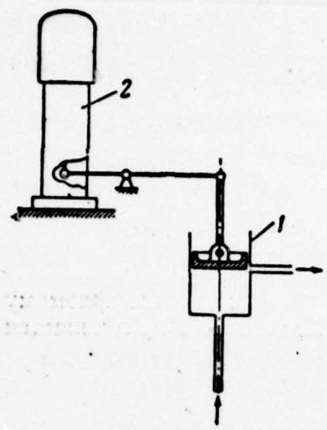

Fig. 62. Pattern of the precise measurement of oil pressure in dynamometer. 1 - hydro-receiver, 2 precision weights.

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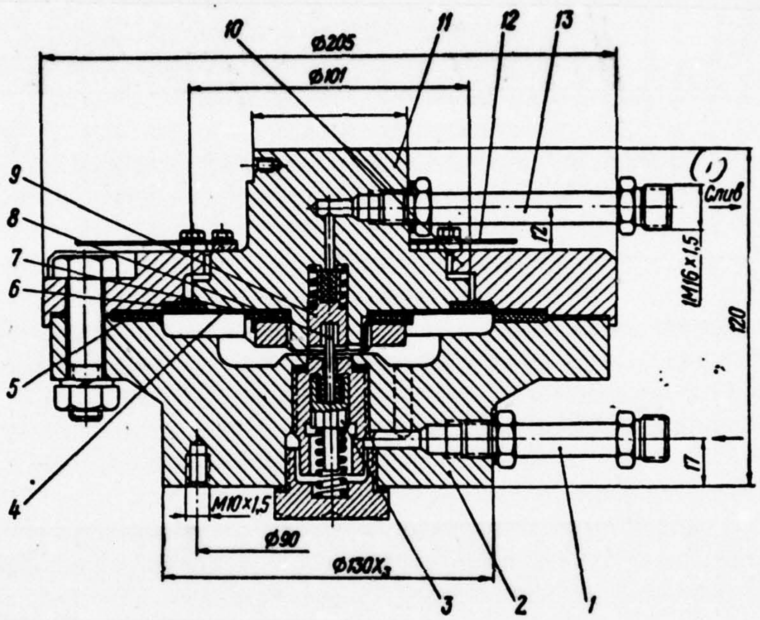

Fig. 63. Construction of flowing dynamometer with the adjustable intake area and oil outlet. 1 - intake branch, 2 cylinder, 3 - intake valve, with spring, 4 - steel diaphragm/membrane, 5, 7 - packing of fiber, 6 - packing rubber, 8 - pusher, 9 - out-gate with spring, 10 - collar, 11 - piston, 12 - the plates, which prevent the misalignment of piston, 13 - output branch.

Key: (1). drain.

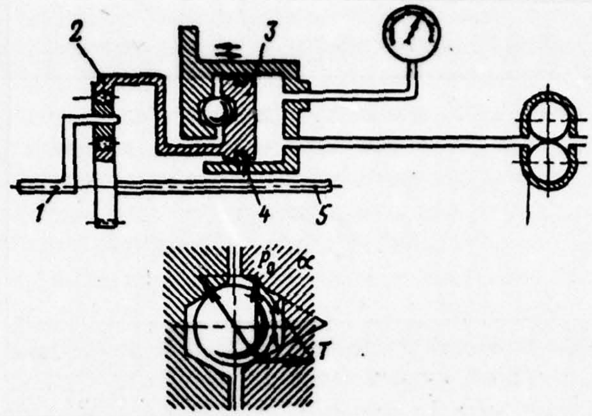

Fig. 64. Schematic diagram of hydraulic IKM with ball/spheres. 1 - the shaft of engine, 2 - gear, 3 - piston, 4 - hole for oil drain, 5 - output shaft.

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Insufficient accuracy/precision of IKM does not make it possible still to forego the bench measuring systems of the torsional moment, although in the operation of turboprop engines IKM they had extensive application.

Spring dynamometers with electric sensors.

In such dynamometers the acting force is absorbed by spring and it deforms it. The deformation of spring can be measured by the inductive, extensometric or other sensor. To Fig. 65, it is given one of the possible diagrams of inductive deformeter. In this diagram the voltage/stress of the output diagonal of the bridge

$$\Delta U = kU\delta, \qquad (103)$$

where k is the coefficient, depending on construction of coils r_1, r_2,

U - the voltage of alternating feed current of bridge,

δ - the displacement of anchor m from free position.

The displacement of anchor δ disturbs balance of bridge and value ΔU is proportional to this displacement. Anchor can be connected with the elastic cell/element, receiving the measured force; thus, the amount of force can be read on the scale of millivoltmeter, correspondingly that which was calibrated completely.

Accuracy of the measurement of force and torque/moment.

Methods described above and instruments for determining effort/forces give different errors.

With the aid of the non-flow dynamometers, oil pressure in which is measured by the piston gauge, the acting forces can be measured with accuracy/precision ±0.2o/o. With that error ±0.1o/o falls on the piston gauge even ±0.1o/o on dynamometer.

Approximately the same accuracy/precision provide flowing dynamometers, but to obtain this accuracy/precision considerably more easily, since in this case is not required absolute airtightness and cleaning air bubbles from system, and also less considerably manifests itself the effect of a change in the ambient temperature.

Spring dynamometers thus far still do not provide the necessary accuracy/precision.

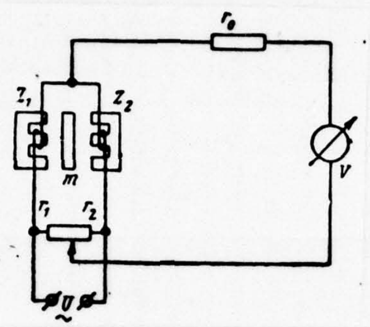

Fig. 65. Diagram of inductive deformeter. m - anchor, z_1, z_2 - magnets, r_1, r_2 - resistance, r_0 - control resistor, U - voltage across terminals.

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6. Measurement of revolutions.

Insturments for determining the engine speed and aggregate/units are called tachometers and total counters. In the practice of tests, won acceptance the mechanical, electromechanical and different magnetic and electrical tachometers, measuring the instantaneous

value of number of revolutions. During testing of gas turbine engines, are applied the tachometers into the range of 1000-20000 r/min; some aggregate/units have large revolutions, for example turbines of aircraft turborefrigerating aggregate/units have revolutions to 100,000 r/min. With very high revolutions the latter are reduced to the value which can be measured by the tachometers, produced by industry, or they are measured by the specially created tachometers.

Total counters measure the sum of revolutions in the determined interval of time.

Total counters.

Total counters are simple, reliable and with constant engine revolutions are characterized by high accuracy/precision. Such counters record the number of revolutions of shaft, made for the determined time interval (1-2 min.).

To Fig. 66, is shown the schematic of total counter.

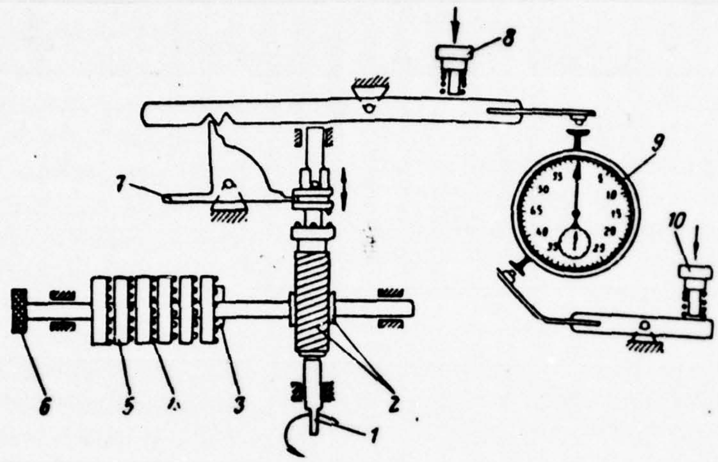

Fig. 66. Schematic of total counter. 1 - driving/homing cylinder, 2 - worm gear, 3 - friction coupling, 4 - the tags of disks, 5 - the disks of counter, 6 - the knob/stick of the jettisoning of counter readouts, 7 - throw-in lever of counter, 8 - the additional knob/button of stopwatch, 9 - stopwatch, 10 - the knob/button of the return of the arrow/pointer of stopwatch to zero position.

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Counting mechanism consists of a series of disks 5 with tags 4, connected consecutively with gear ratio 1/10. If right wheel makes

1000 revolutions, then following after it 100 revolutions, that follows 10 and so forth. On the surface of disks, there are numerals, thanks to which it is possible to read number in decimal system.

On cylinder 1, freely sits the worm, and to as long as it it is not coupled beaded, computing mechanism does not work. If we build up lever 7 upward, then is clutch, after being drop/omitted, it will connect worm beaded 1 it will include/connect computing mechanism. Simultaneously it will occur and the connection/inclusion of stopwatch 9. To stop counter is possible by pressure lever 7. Knob/button 10 serves for the return of stopwatch to zero position, while knob/button 8 is for the independent starting/launching of stopwatch.

Electrical tachometers.

Let us examine operating principle and the elements of the construction of the magnetic-induction tachometer of type ITE-1 (Fig. 67). During the rotation of the rotor of 2 sensors in the winding of stator 1, is excited three-phase current with the frequency, proportional to engine revolutions. Current on wire/conductors is transferred to the winding of the stator of 6 synchronous motor of

the meter of revolutions and rotates its rotor 4.

On the rotor shaft of engine, is fastened a 12-pole six-conjugate magnet 5. Between magnet poles, is arrange/located sensing element - disk 7 in which during the rotation of magnet are induced the eddy currents. The torsional moment, applied by magnetic field to disk 7, is proportional to engine revolutions. Helical spring 8 balances the effective torque/moment; thus number of revolutions is measured by the angle of rotation of arrow/pointer 11 and the value of number of revolutions absolute or in percentages they are read on scale 10.

For the damping of measuring system used magnetic retardation; between fixed magnets 12 on the cylinder of arrow/pointer 11 is attached aluminum disk 9 in which are aimed the eddy currents.

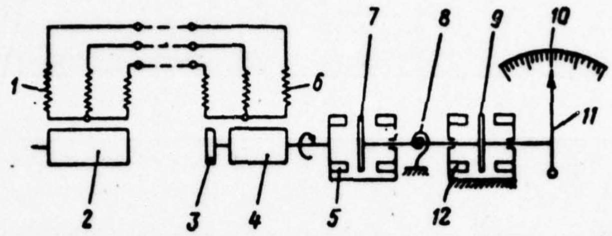

Fig. 67. Schematic diagram magnetic-induction tachometer ITE-1. 1 - the winding of the stator of sensor, 2 - the rotor of sensor, 3 - hysteresis disks, 4 - the rotor of meter, 5 - six-conjugate magnet, 6 - the winding of the stator of synchronous motor, 7 - sensing element, 8 - spring, 9 - aluminum disk, 10 - the scale, 11 - pointer, 12 - fixed magnets.

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The interaction of the magnetic fields of disk and magnets is led to the appearance of braking, damping torque/moment.

On Fig. 68, is given the longitudinal section of the meter of tachometer. Meter consists of two assemblies; synchronous motor and

the mechanism of meter.

Synchronous motor consists of stator 17 and rotor 4, carried out in the form of two cruciform magnets 5 and of the cell/element of starting/launching - three hysteresis disks 3, arrange/located on sleeve 2. The permanent magnets are arrange/located on shaft freely and are connected with it with the aid of spring 6, through which they transfer shaft torque of engine.

Magnetic assembly 8 consists of two pay/boards with pressed-in of them permanent magnets 9. Opposite of magnet pole on walk against each other and concentrate magnetic flux around the periphery edges of sensing element (disk) for obtaining maximum torque. The mechanism of meter has sensing element 10, arrange/located in air gap of the magnetic assembly between the end/faces of cylindrical magnets.

Arrow/pointer 11 shows on the scale of 12 meters number of revolutions per minute of the shaft of aircraft engine. Material of sensitive cell/element is the aluminum-magnesium alloy, which has the low temperature coefficient of electrical resistance, thanks to which temperature change does not have considerable effect.

The temperature compensation in meter is realize/accomplished as follows: to the magnets of 9 magnetic assembly, is installed magnetic

shunt 16, manufactured from the special alloy whose magnetic permeability with an increase in the temperature is decreased, and with a temperature decrease, it increases. With constant/invariable temperature of the environment, the shunt draws off on itself the part of the working magnetic flux and thereby decreases the working flow in the clearance between magnet ends of magnetic nodes.

With an increase in the temperature the working magnetic flow in the gap increases, while during decrease in the temperature - it is decreased. A change of working magnetic flow in the gap because of a change in magnetic permeability of shunt will agree with a change in the electrical resistance of sensing element, retaining by almost constant/invariable the value of torque of system, created by magnetic assembly.

The assembly of sensing element is fastened on three struts by 14 adjusting nuts 15. In instrument there is a special magnetic assembly, as a result of action of which the movable system obtains braking torque/moment, which raises the stability of arrow/pointer.

Sensor DTE-2 of tachometer (Fig. 69), used together with indicator ITE-1, is three-phase a-c generator with constant four-terminal magnet as rotor.

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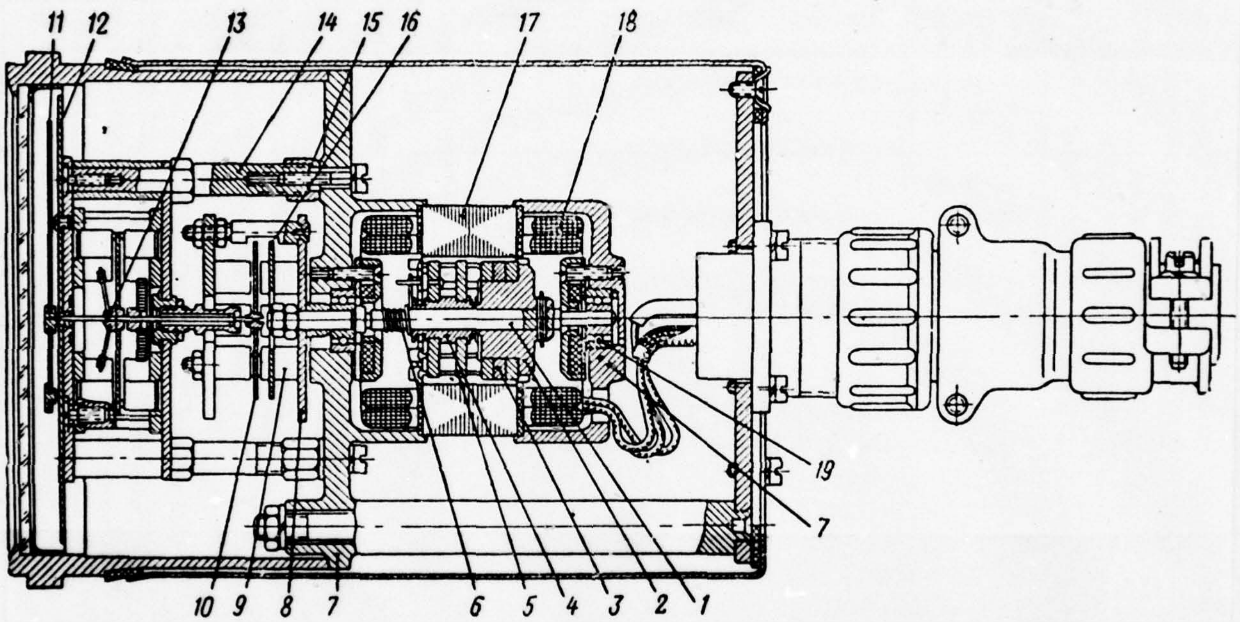

Fig. 68. Meter of tachometer ITE-1. 1 - shaft, 2 - sleeve, 3 - the cell/elements of starting/launching (disks of hysteresis), 4. rotor, 5 - cruciform magnets, 6 - spring, 7 - cap/cover, 8 - magnetic assembly, 9 - the permanent magnets, 10 - sensing element, 11 - rifleman/gunner, 12 - the scale, 13 - axle/axis, 14 - strut, 15 - adjusting nuts, 16 - shunt, 17 - stator, 18 - three-phase winding, 19 - ball bearings.

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Rotor 2 they cast from the alloy ANK, which possesses high induction and considerable coercive force. Rotation from shafting of aircraft engine to the rotor of sensor is transferred with the aid of stem 4.

Stator 1 for decrease in it in the losses from eddy currents is collected from the plates of transformer iron. The plates of stator are isolate/insulated from each other. The stator winding - four-terminal three-phase, is made from copper wire. Each phase of the stator winding has 4 coils. The connection of phases by star and the connection of the installation wires, which go from meter to sensor, produce with three-pronged jack 6. With adapter nut 5 sensor is fastened to the drive of aircraft engine.

Together with the sensor DTE, is applied also more precise standardized ferrodynamic bench tachometer TSFU tsfu-1.

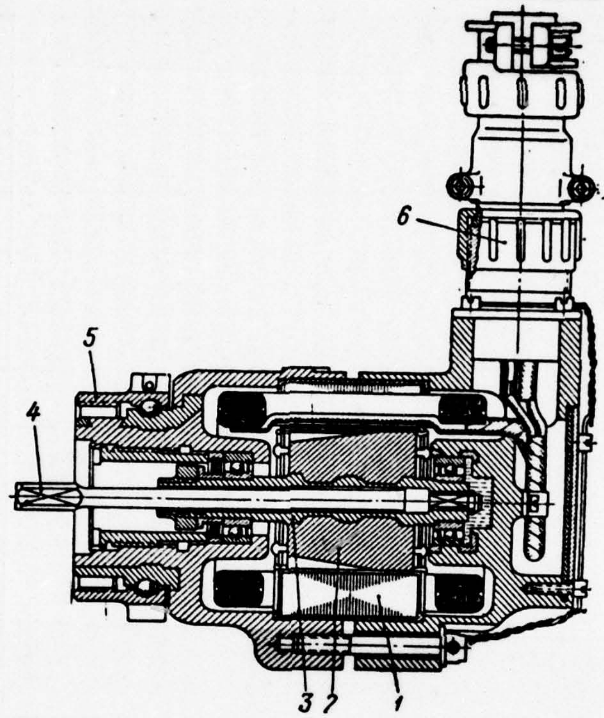

Fig. 69. Sensor of tachometer DTE-2. 1 - stator, 2 - rotor (four-terminal magnet), 3 - shaft, 4 - stem, 5 - the adapter nut, 6 - three-prong jack.

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The current frequency of sensor, proportional to the revolutions of the shaft of aircraft engine, in this case is measured by the

frequency meter, carried out according to resonance-compensating schematic (Fig. 70).

For the measurement of frequency in schematic, is utilized the compensating ferrodynamic logometer of alternating current with steel magnetic circuit 1. For the projection of yoke 1, is wound coil 3. Mobile coil-frame 4 can be turned around axle/axis - steel core. Pointer 2 showing revolutions is attached on mobile framework 4. Framework 4 is closed to throttle/choke 5. During the passage of the current through coil 3 in yoke, appears the alternating/variable magnetic flux, which induces emf E_e and calling the appearance of a current within coil-frame 4. As a result of the interaction of the fields of the yoke and coil-frame, appears torque M, which attempts to turn arrow/pointer 2 for position 00, to what contributes the inductance of throttle/choke 5. The effective torque/moment is obtained as a result of the supply of variable voltage U and of the appearance of emf E_x in circuit with condenser/capacitor C_0 and effective resistance r_0.

Fixed coil 3 feeds from the same source of variable stress U through condenser/capacitor C. The current of the framework I_x is function E_e, induced within framework 4, and also E_x, that which was conducted to the framework of measuring circuit. Role E_x fulfills voltage on throttle/choke 5.

Torque of ferrodynamic measuring mechanism depends on the value of the current of the framework I_{R}, of the magnetic flux of fixed coil Φ_{s} and of the phase angle between them:

$$M = k\Phi_{\text{s}} I_{\text{R}} \cdot \cos\varphi. \quad (104)$$

Schematic is comprised so that the inductance of fixed coil 3 and the capacitance of series-connected capacitor C at the average/mean value of the measured frequency of this range of revolutions would be found in resonance.

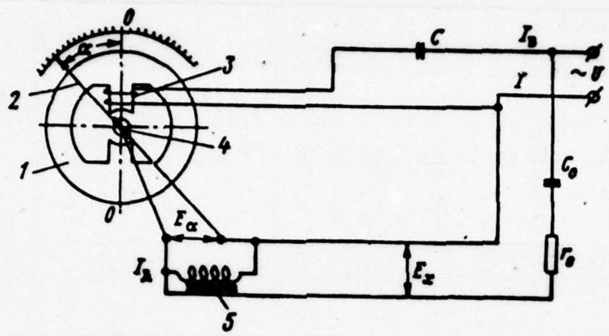

Fig. 70. Schematic diagram of resonance-compensating frequency meter. 1 - yoke-magnetic circuit, 2 - pointer, 3 - coil, 4 - coil-frame, 5 - throttle/choke.

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The capacitance/capacity of parallel circuit C_0 the effective resistance of parallel circuit r_0, the inductance of throttle/choke 5 and the effective resistance of framework 4 are selected so that at the medium frequency of the measured frequency band the current within the framework $I_{\text{л}}$ was shifted relative to the flow fixed coil Φ, to angle of 90°. With such relationship/ratios the torque/moment of the framework is equal to zero, movable part it is located in equilibrium, and the rifleman/gunner of instrument shows the middle

of the scale.

During frequency change to any side, is disturbed the resonance in the circuit of fixed coil 3 and the phase angle ϕ of the current of the framework $I_{\text{я}}$ becomes no longer equal to 90° relative to magnetic flux $\Phi_{з}$. Torque/moment M of the framework in this case no longer equal to zero and the framework diverges to the right or to the left from the mid-position until the phase angle ϕ between the current of the framework $I_{\text{я}}$ and the magnetic flux $\Phi_{з}$ of fixed coil again becomes equal to 90°. Torque again proves to be equal to zero and the framework is stopped in the new of positions of equilibrium, which corresponds to angle α. Because of the inductance of throttle/choke 5 in the circuit of the framework, is provided true equilibrium of the moving element of the logometer.

To each value of frequency within the limits of this range corresponds the determined angle α of throw of pointer from free position 00. Dial face can be graduated in the portions of revolutions, revolutions or hertzes.

The meter of the described diagram possesses good accuracy/precision, weak sensitivity to the fluctuations of value and forms of cue voltage.

Testing tachometers and accuracy of the measurement of revolutions.

In given below Table 12 is shown the effect of an error of measurement of revolutions on the accuracy/precision of the determination of thrust/rod and specific consumption of the fuel/propellant of one turbojet engine with n = 12 000 r/min.

Tables 12.

(1) Погрешность измерения числа оборотов		(2) Относительная ошибка в %	
(3) абсолютная (об/мин)	(4) относительная %	(5) тяги	(6) расхода топлива
10	0,083	0,38	0,32
20	0,167	0,80	0,63
40	0,333	1,57	1,27
80	0,667	3,13	2,60

Key: (1). Error of measurement in the number of revolutions. (2). Relative error, in o/o. (3). absolute (r/min). (4). relative o/o. (5). thrust/rod. (6). the fuel consumption.

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The precise measurement of number of revolutions can be reached under the condition of applying the high-quality tachometers of their systematic testing. Tachometers are checked by means of the comparison of their readings with data of control tachometer. As monitoring instrument are accepted total counters, precise hour tachometers, the crystal or tuning fork-electron-tube oscillators of frequency.

One Of the possible installation diagrams for the control/check of tachometers it is represented on Fig. 71. Installation consists of electric motor 5, which can be moved with the aid of lever 3 and the friction drive, which consists of small disk 2 and large disk 1. To the shaft of friction drive, are connected checked and control tachometers 4 and 7. Friction drive makes it possible to smoothly change the revolutions of tachometers in necessary range. The accuracy/precision of the calibration of tachometer depends on the accuracy/precision of control tachometer.

The accuracy/precision of total counters is sufficiently high: during the measurement of revolutions during 60 s., the error in measurement of time is obtained by 0.03-0.05 s., which gives error with the evenly running shaft of the engine of order +-0.1o/o.

The accuracy/precision of the magnetic-induction tachometers ITE-1, ITE-2 is characterized by data given in Table 13.

Larger accuracy/precision possess the bench ferrodynamic tachometers of types FT-49 and FT-49/13.5; error of FT-49 does not exceed +-0.5o/o, and error of FT-49/13.5 does not exceed +-0.35o/o.

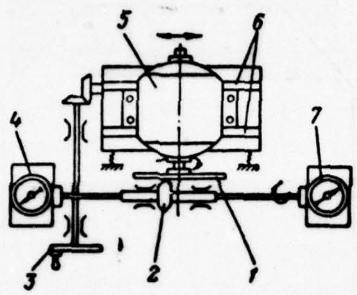

Fig. 71. Installation for the control/check of tachometers. 1- large disk of friction drive, 2 - small clutch plate, 3 - lever for displacing electric motor, 4 - the checked tachometer, 5 - electric motor, 6 - directing of electric motor, 7 - control tachometer.

Table 13. Accuracy/precision of the magnetic-induction tachometers ITE-1, ITE-2 depending on temperature.

(1) Предел измерений %	(2) Погрешность в % при температуре в °С		
	+20	+50	−60
10—60	±1,0	±1,5	±2,5
60—100	±0,5	±1,0	±1,5
100—105	±1,0	±1,5	±2,5

Key: (1). Capacity. (2). Error in o/o at the temperature in °C.

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Very good accuracy of the measurement of revolutions provides bench tachometer TSFU-1 (error of measurement it does not exceed +-0.2o/o).

7. Measurement of the rapidly changing values.

The rapidly changing values in VRD [ВРД - jet engine] measure with the special sensors, which convert the nonelectric parameters into electrical whose change is record/fixed by oscillographs. The recording of the rapidly changing revolutions is necessary during the study of transient processes of the engine. Measurement of the rapidly changing pressures and temperatures makes it possible to study such important processes as surge and the excesses of temperature.

The steadiness of engines - one of the most important indices of their suitability to operation. Equilibrium can be estimated, after recording frequency and the amplitude of the vibrations of housing. The recording of the vibrations of the parts of compressors and

turbines helps to determine resonance engine operating modes and to remove a breakage in the parts from oscillation/vibrations.

Let us examine below the device of oscillographs and sensors for the recording of vibrations, revolutions, rapidly changing pressures and temperatures.

Oscillographs for the recording of the rapidly changing processes.

Oscillographs are applied magnitoelectric (train) and electronic (cathode).

Fig. 72, shows the schematic of the tail (or vibrator) of magnitoelectric oscillograph. Tail consists of permanent magnet 4, in field of which is located current-conducting loop 1, by stretched spring 5 and which rests on two insulating prisms 2. To loop is stuck mirror 3. If through the loop passes alternating along amplitude current, then due to the interaction of the fields of loop and magnet mirror will oscillate and the falling/incident to it ray/beam will diverge. For the damping of oscillation/vibrations after the disappearance of driving pulses, this system is immersed in oil. The frequency of record/written by such loops oscillations does not

exceed 10 000 Hz.

Fig. 73, shows the optical diagram of loop oscillograph. Light beam from bulb 1 passes through 2 and diaphragm 3; with the aid of refracting prism 4, it heads for the mirror of loop 10.

Under the effect of alternating current, passing through the loop of circuit, the mirror oscillates and the beam of light, which goes to deflecting prism 9, also oscillates.

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The part of the ray/beam, passed through deflecting prism 9, falls on rotating angular mirror drum 8. Because of the faces of drum 8, it is possible to obtain scanning ray/beam from time and to observe the curve of process on matte screen 5.

The part of the ray/beam, which passes above prism 9, through cylindrical lens 6 falls on rotating drum 7, on which is located the photographic paper. Along with the curve of process on photographic paper, he is record/written the sinusoid curve the period of oscillation/vibration of which is accurately known (for example, 500 Hz). This curve gives one of the tails of oscillograph, called time

marker. The curve of time marker is design/projected also for matte screen 5.

Wide acceptance in our industry obtained universal eight-loop magnitoelectric portable oscillograph MPO-2. It is convenient in operation, has small dimensions and weight. The optical recording of processes in it is produced to the motion picture film with a width of 35 mm up to 5 m/s in speed. Because of large sensitivity of motion picture film in MPO-2 as the light source is applied the electric lamp by the power altogether only 7.5 W.

For recording of high-frequency oscillations, are applied electron oscillographs (Fig. 74).

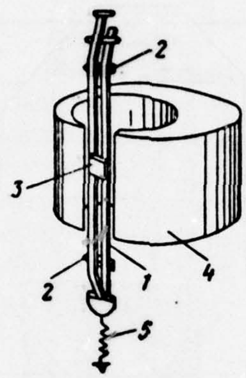

Fig. 72. Tail of magnitoelectric oscillograph. 1 - loop, 2 - the knife edge, 3 - mirror, 4 - magnet, 5 - tension spring.

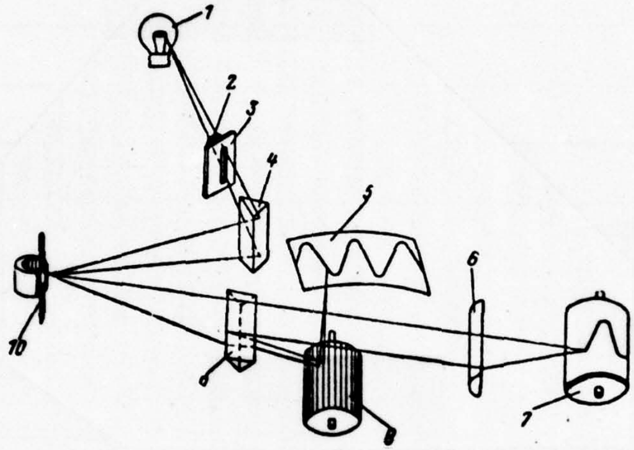

Fig. 73. Schematic of loop oscillograph. 1 - the light source, 2 - condenser, 3 - diaphragm, 4 - the refracting prism, 5 - the matte screen, 6 - cylindrical lens, 7 - drum with photographic paper, 8 - angular mirror drum, 9 - the deflecting prism, 10 - tail.

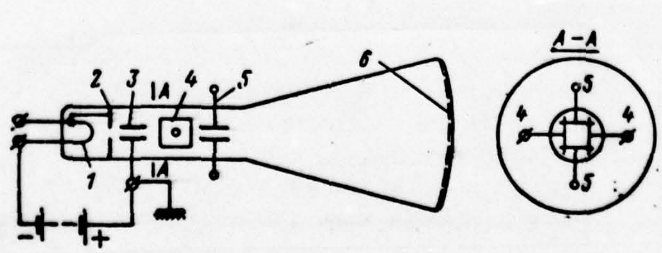

Fig. 74. Schematic of cathode-ray oscillograph. 1- cathode, 2 - diaphragm, 3 - the anode, 4, 5 - the deviating/deflecting plates, 6 - shield.

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Incandescent cathode 1 emits the electrons which are passed through the slot in diaphragm 2 and are accelerate/dispersed with the electric field of anode 3; narrow electron beam passes between deviating/deflecting vertical and horizontal plates 4 and 5. Each of the pairs of plates has the isolated/insulated conclusion/derivations from tube. On of the pairs of plates it is connected to the voltage, which changes according to that determined, for example, to linear law. To the second pair of plates, is connected the studied voltage. Under the effect of the fields of plates, the ray/beam is described curve on shield 6, covered with the fluorescing composition. With the aid of photo attachment the curve can be photographed and then studied.

Measurement of engine vibration.

During testing of full-scale engines, they are record/written

their vibration. Instruments for the measurement of vibrations call vibrographs. They consist of sensors, the integrodifferentiating amplifiers and indicator. Thus, for instance, in the assembly of the vibrograph AV-42 enters 6 sensors (4 horizontal and 2 vertical), 3 integrodifferentiating amplifiers, switchboard and the connection hoses. Readings of vibrograph can be recorded with any loop oscillograph.

We will be restricted to the examination of the device of the sensor of vibrograph (Fig. 75). Heavy magnet 4 with the aid of axle/axes 8 is supported in bearings 6, pressed by cap/covers 1, and it can freely be moved along housing.

Springs 2 and 5 are the resilient mountings of magnet. The natural frequency of the system of spring - magnet is considerably lower than the frequency of the engine being investigated or assembly; therefore during engine vibration, magnet remains fixed (along axle/axis), and the housing of sensor, fixed by flange 9 to engine, oscillates. Magnetic flux is passed through clearances and is closed to the iron housing of sensor.

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Magnet is inserted into coil 3 with the winding whose one end emerges

to terminal 7, and another is connected with the housing of sensor.

As a result of the motion of the housing of sensor and coil relative to magnet in coil is induced emf whose value is determined from the formula

$$E = cv, \qquad (105)$$

where E - emf in mV; c - coefficient in mV s/mm; v - the speed of relative motion in mm/s.

Sensitivity of sensor is determined from the formula

$$K = \frac{E}{fs}, \qquad (106)$$

where s is amplitude of vibrations in mm; f is a vibration frequency in Hz.

Since a change in emf of proportionally to the speed relative motion of housing and magnet, in amplifier is included the schematic of differentiation of emf and its integration; integration gives displacement/movement curve, and differentiation - accelerations.

Vibrograph normally works at frequency 20-300 Hz; to the amplitude of acceleration 0.5-10.0 g, to the amplitude of speed 10-375 mm/s, to the amplitude of displacement 0.02-1.5 mm.

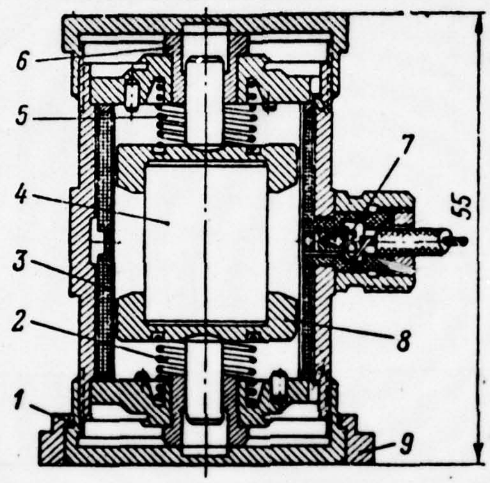

Fig. 75. Sensor of vibrograph. 1 cover, 2, 5 - spring, 3 - coil, 4 - magnet, 6 - bearing, 7 - terminal, 8 - the axle/axis of magnet, 9 - flange.

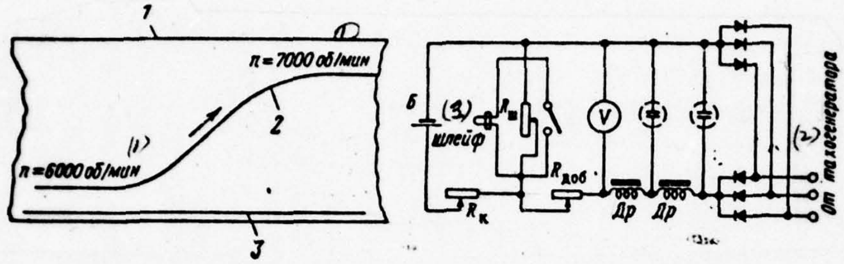

Fig. 76. Circuit of the recording of the instantaneous value of angular velocity and the specimen/sample of oscillogram. 1 - oscillogram, 2 - is curved of revolutions, 3 - base line.

Key: (1) r/min. (2). From tachogenerator. (3). Tail.

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Measurement of the rapidly changing revolutions.

An oscillograph can be utilized as total revolution counter and for the recording of the instantaneous value of angular velocity. Fig. 76, gives schematic for the recording of the instantaneous value

of angular velocity and the specimen/sample of oscillogram. The voltage of three-phase tachogenerator is fed to the selenium rectifier. For the smoothing of pulsations into schematic, is included the filter.

Rectified constant voltage V is fed through the additional resistance $R_{доб}$ to the shunted ($R_{ш}$) tail of oscillograph. For sensitization, the schematic is equipped by the compensating duct in which enters the battery B and resistance $R_{к}$. The currents of source B and of tachogenerator are deducted; during a change in the revolutions, a difference in the currents is changed, which is led to the deflection of the tail of oscillograph.

Measurement of the rapidly changing pressures.

For the measurement of the rapidly changing pressures, they apply two groups of the sensors:

1) the sensors, sensing element of which are elastic diaphragm/membranes;

2) the sensors whose sensing element changes its physical

properties under the effect of the changing pressure.

The first group of sensors includes capacitive, the meters with the wire-strain gauges, inductive, ion-mechanical, optico-membrane/diaphragm, magnetocompensating.

To the second group of sensors, are related piezoelectric, magnetostrictive, electrokinetic, radioactive-ionizing, carbon.

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With the operating principle of these sensors, it is possible to become acquainted in detail according to G. P. Katys's book. [1].

FOOTNOTE [1]. G. P. Katys, methods and instruments for the measurement of the parameters of nonstationary thermal processes, Mashgiz [Машгиз - State Scientific and Technical Publishing House of Literature on Machinery Manufacture], 1959. ENDFOOTNOTE.

Let us examine the operating principle of the most frequently used inductive and piezoelectric quartz crystal sensors.

Fig. 77, shows pressure unit with inductance pickup. In this sensor under the action of pressure differentials, is deflected diaphragm/membrane 3. With sagging/deflection is disturbed bridge balance in which is included the sensor and this disturbance/breakdown it is recorded in the final analysis with oscillograph.

This receiver depending on the thickness of diaphragm/membrane can be utilized for recording of different pressure differentials. Thus, for instance, with the thickness of diaphragm/membrane 0.025 mm it is possible to measure the jump/drop from 0 to 0.05 kg/cm², and with thickness 0.20 mm, are from 0 to 5 kg/cm². Because of the low size/dimensions of the cavities the distortions of measured drops do not exceed 10o/o to frequencies 400 Hz. Receiver has insignificant weight and can be made miniature/small.

Piezoelectric quartz crystal sensor for the measurement of the rapidly changing considerable pressures (order of several dozen atmosphere) is shown in Fig. 78. This sensor enters in piezoelectric quartz crystal indicator.

Most important element of sensor is quartz plates 6 with pressed between them isolated/insulated slip ring 5.

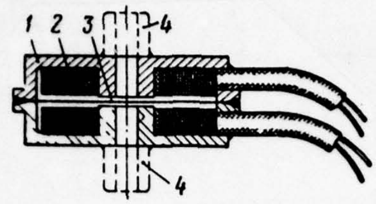

Fig. 77. Pressure unit with inductance pickup. 1 - magnetic circuit from Permalloy, 2 - winding, 3 - diaphragm/membrane, 4 - branch for the supply of pressure.

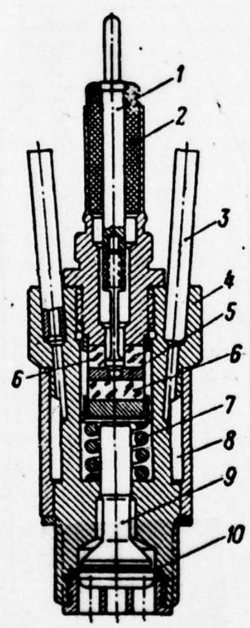

Fig. 78. Piezoelectric quartz crystal sensor for the measurement of the oscillating pressures. 1 - the isolated/insulated conclusion/derivation, 2 - insulator, 3 - water pipe, 4 - the housing of sensor, 5 - the isolated/insulated electrode, 6 - quartz plates, 7

- the spring of the precompression of the column of quartz plates, 8 - coolant passage, 9 - cap for the transfer of effort/force to quartz plates, 10 - sealing diaphragm/membrane.

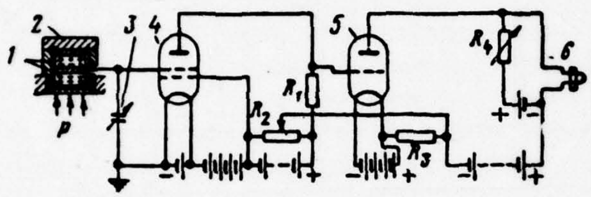

Fig. 79. Schematic diagram of piezoelectric indicator. 1 - piezoelectric quartz crystal plates, 2 - piezoelectric quartz crystal sensor, 3 - condenser/capacitor, 4 - electrometer tube, 5 - amplifier tube, 6 - the tail of oscillograph.

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The variable pressure of gases is transferred through sealing diaphragm/membrane 10 and cap 9 to the piezoelectric quartz crystal plates, which convert the work of forces of pressure into electric power. So that the sensor would not be overheated, it is cooled by water.

Fig. 79, shows one of the possible schematics of piezoelectric quartz crystal indicator. Piezoelectric quartz crystal plates are

arrange/located so that the electric charges, which are formed as a result of their compression, have one sign (minus) and are remove/taken by slip ring. Positive charges depart to mass. The value of the appearing charges is proportional to the effective effort/forces. Thus, force measurement in such indicators is replaced by the measurement of electric charges.

As the meter of charges, is applied the vacuumtube voltmeter. Charge from quartz plates 1 is fed to condenser/capacitor 3 and control grids of electrometric tube 4. Under the effect of the created potential changes the anode current of tube, which can be in principle measured by galvanometer. This current will be proportional to the acting on quartz plates force. The current of tube 4 too weak; therefore it is strengthened with the aid of tube 5.

In the anode circuit of tube 5, is connected the tail of 6 oscillograph. In parallel to tail 6 through adjustable resistor R_4 is included battery for the compensation for the zero current of amplifier. Piezoelectric quartz crystal indicators are used extensively during the study of fluctuations of pressure.

A shortcoming in the piezoelectric quartz crystal sensors is the dependence of the value of piezoelectric effect from temperature. At temperature of 570°C, quartz completely loses property to create

electric charges under effect of pressure.

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Accuracy of the measurement of the rapidly changing values.

To determine the accuracy of the measurement of the rapidly changing values is very complicated. Vibrograph described earlier AV-42 gives a basic error in the determination of any parameter of vibration without taking into account of an error in interpretation +-10o/o in frequency range 25-300 Hz and +-15o/o in frequency range 20-25 Hz.

An error of measurement angular variable speed is composed of an error in the time marker and interpretation of oscillograms. The accuracy/precision of interpretation can be increased because of an increase in the velocity of the movement of photographic paper. An error in the tails with oil damping reaches to +-3o/o, and with electromagnetic - to +-1.5o/o.

An error in the meters of the rapidly changing pressures is evaluated at 5-7o/o and is comprised from errors in the receiver,

amplifier and oscillograph.

8. Measurement of oscillations and temperature of rotating parts.

Is developed a series of the methods of the measurement of oscillations and temperature of rotating parts. So, for the recording of oscillations are applied capacitive and strain gauges, the sensors of the carbon type, etc. For the measurement of the temperature of parts, are applied the thermocouples, the method of measurement according to the scale of hardness, with the aid of fuse links, thermocolors, etc. Let us examine widespread method of the measurement of oscillations with the aid of strain gauges and the method of the measurement of the temperature of rotating parts with the aid of thermocouples.

Oscillation measurement with the aid of strain gauges.

Oscillation measurement with the aid of strain gauges is based on the use of a property of some metals to noticeably change its ohmic resistance during deformation. As materials for strain gauges,

are applied constantan, Nichrome, Manganin, Chromel, etc. In strain gauges usually is utilized the wire with a diameter of 0.01-0.03 mm. The wire is glued up between the strips of fine/thin paper in the form of flat/plane loops, as shown in Fig. 80. Strain gauges stick on the part being investigated with which they together transform.

During deformation Δl mm of resistance strain gauge its is changed according to the law

$$\Delta R = kR\frac{\Delta l}{l}, \qquad (107)$$

where ΔR is a change in the resistance of wire; k - strain gauge factor; R is an initial resistance; l is length of wire with zero voltage.

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The accuracy of measurements with the aid of strain gauges in essence depends on their quality and the quality of gluing. The surface of part are worked with purity/finish not below $\nabla 6$; the primes of treatment must be furnished perpendicular to the loops of sensor. For cementing and gluing, are applied the glues: celluloid, carbinol, bakelite, bakelite-phenol (BF-2, BF-4), etc.

Strain gauges with the aid of wire/conductors are connected in

the measuring system, fulfilled usually according to the schematic of potentiometric or single bridge.

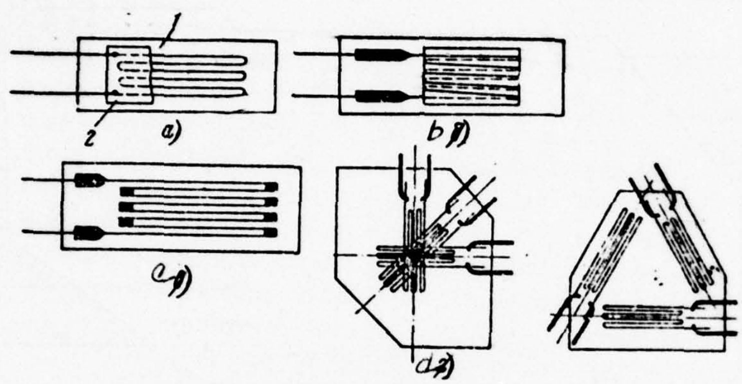

Fig. 80. Types of strain gauges. a is a strain gauge for a base 5-25 mm, 1 - the lower layer of paper, 2 - an upper layer of paper, b - strain gauge for bases 5 mm and less with fish winding, c - strain gauge of foil with the smaller coefficient of transverse strain sensitivity, d - strain gauges for the analysis of the complex stressed state.

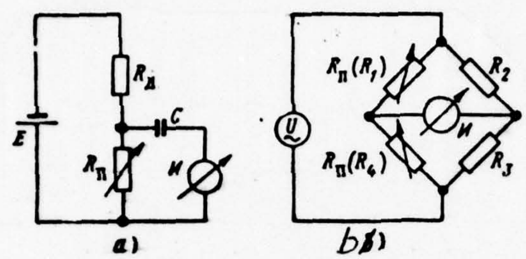

Fig. 81. Connections of strain gauges. a is a schematic of potentiometric switching on, $R_Д$ - resistance, $R_П$ - strain gauge, C - condenser/capacitor, $И$ - meter (electron oscillograph), b are a schematic of single bridge, $R_2 R_3$ - resistance, R_1 and R_4 - strain gauges.

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The schematic of potentiometric switching on (Fig. 81a) is applied when they are interested only in variable component of resistance. The constant component resistance they precipitate on converter $R_П$ by condenser/capacitor C. As meter $И$ usually is utilized the oscillograph.

More considerably frequently apply the schematic of the single bridge (Fig. 81b), in one or two arms of which connect working

converters. For dynamic measurements usually is utilized the schematic of nonequilibrium bridge. In this case the measurement is conductn directly from reading of meter *И*, connected in diagonal bridge.

Since a change in the resistance of strain gauge very little, should special attention focus on the compensation for a change in its resistance due to the fluctuations of temperature, and also to the effect of a difference in the coefficients of the expansion of part being investigated and material of strain gauge. Temperature effect on the accuracy of measurement can be considerably attenuate/weakened by the inclusion into adjacent bridge arm (on opposite side of measuring diagonal) of the special compensating sensor for which are created the same temperature conditions that and for a basic.

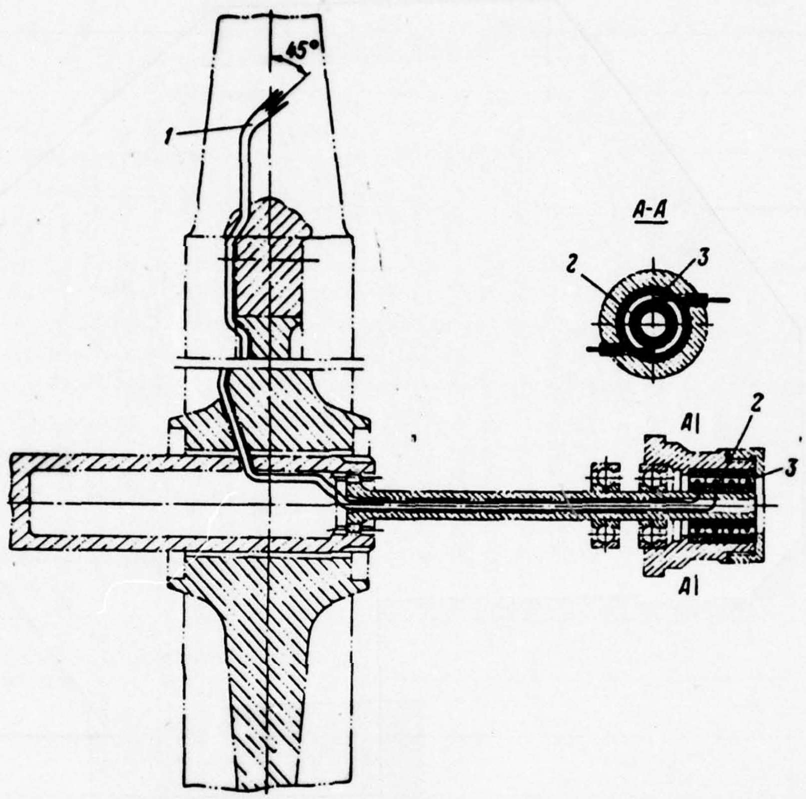

Fig. 82. Arrangement of strain gauge on blade and the schematic of wiring/run from strain gauge to slip ring. 1 - strain gauge, 2 - the silver electric insulated rings, 3 - brush.

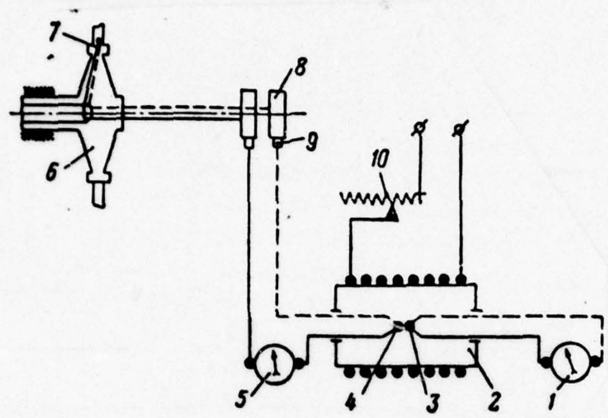

Fig. 83. Measuring circuit of temperature by compensation method. 1 - the millivoltmeter of fixed thermocouple, 2 - thermostat, 3 - the junction of fixed thermocouple, 4 - the cold-soldered joint of the rotating thermocouple, 5 - zero-adjustment instrument, 6 - turbine rotor, 7 - hot junction of the rotating thermocouple (is establish/installed in part), 8 - contact disks, 9 - the sliding clamped contacts, 10 - rheostat.

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Fig. 82, gives an example of gluing strain gauge on compressor blade. Transmission of current to strain gauge and from it, with the insignificance of current itself and its oscillations, represents difficult task. In the case in question it is solved as follows.

The wiring/run of strain gauge 1 is connected to the electric insulated silver rings of 2 anchors of slip ring; on these rings slip fixed brushes 3 of the constantan wire with a diameter of 0.2 mm. Brushes 3 are pressed against rings 2 by elastic force and provide a good current pickup with the insignificant wear of rings.

Measurement of the temperature of parts.

The measurement of the temperature of stationary parts does not usually present special difficulties. Thermocouple is filled up into part and its wire/conductors are lead off as much as possible over isothermal surface (for decrease in the heat withdrawal from the regulus of thermocouple). Considerably the complex problem of the measurement of the temperature of the rapidly rotating parts, for example blades and turbine disks.

Let us examine the method of measurement of the temperature of the blades by compensation method with the aid of thermocouples, shown in Fig. 83.

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Hot junction of 7 thermocouple is sealed into blade. Wire/conductors on turbine disk and shaft are matched up disks 8 with the contacts, made from silver. For wire insulation, are applied steatitic tubes. Wire/conductors connect up disks by soldering.

Contact disks 8 transfer current to sliding contacts 9 of the constantan wire. The current of measuring thermocouple is compensated for by the current of cold-soldered joint 4, submerged in thermostat 2. The temperature of thermostat measures with fixed thermocouple 3. At the torque/moment when the temperatures of the joint of 7 joint 4 are equal, highly sensitive mirror galvanometer 5 shows zero current.

The advantage of compensation method is a considerable reduction/descent in the role of contact resistance in circuit and therefore the increased accuracy of measurements. A shortcoming in this method is the duration of experimentation due to the thermal inertia of thermostat.

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Chapter IV.

Testing laboratories of engines, their assemblies and aggregate/units.

Laboratories are organized with the experimental design bureaus of plants, in scientific research and academic institutes.

Primary task of plant laboratories is an adjustment of operating conditions and strengths of aggregate/units and engine components above which works this plant or the group of plants.

In the laboratories of institutes, are carried out scientific research works in the region of operating conditions of engines and their aggregate/units, and also intensified research on the characteristics of engines and their cell/elements.

High-altitude stands of full-scale engines usually are located in the system of scientific research institutes.

1. General information about the equipment of laboratories.

To experimental laboratories present the following basic requirements:

1) the equipment of laboratory must correspond to assigned before it missions;

2) the systems of measurements must provide precise and rapid recording of the necessary values;

3) laboratories must be provided with all forms of power feed/supply;

4) combustion products of fuel/propellants and spent fluids must not contaminate the surrounding space;

5) testing units must have sound-deadening devices.

Let us examine power-supply systems and the basic equipment of laboratories.

Pneumatic system.

The pneumatic systems of installations are more complex than the similar systems of plant experimental stations, especially in the case of the imitation of flight conditions.

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For obtaining on the engine inlet of the necessary speed and air pressure, is compressed in special blowing plants, it is preheated either is cooled in heat exchangers, is dried or is moistened. In the units of short-term action, the air is preliminarily pumped by compressor into receivers (bottles) and during tests is fed to engine. In the units, intended for endurance tests the air is fed to engine from the compressor, which ensures the necessary flow rate and air pressure.

For air compression, are applied the centrifugal or axial-flow compressors, driven by electric motors, steam or gas turbines. Piston compressors find a use when is necessary a comparatively small quantity of air with large pressure (for example, for pulse installations with receivers).

To obtain the necessary air speed at the engine inlet is possible and by other methods, for example, using as blowers a series of TRD [turbojet engine] whose part of the air is take/selected directly after supercharger and is fed to the common/general/total pneumatic system, which feeds engine. The advantages of the application/use of a series turbojet engine for obtaining air with the comparatively high parameters are explained by the compactness of the obtained unit, which combines in one aggregate/unit the source of thickness - turbine, strictly the source of air - compressor and all the necessary power supply units, cooling and regulation.

In the most widely used schematic of blower on base of TRD (Fig. 84) decrease in the quantity of gas, passing through the turbine of engine, is compensated for by the expansion/disclosure of jet nozzle. Thus turbine works on pressure differentials increased in comparison with design. For the increase in the service life of engine, utilized as blower, it follows as far as possible to restrict the temperature of the gases before turbine value T^*_3 = 800-850°K.

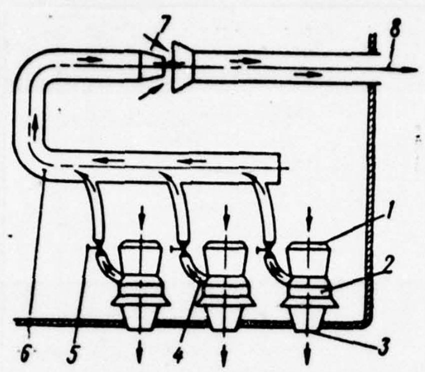

Fig. 84. Schematic of blower with air bleed after compressors of turbojet engines. 1 - the entry of air in TRD, 2 - TRD, 3 - the ejection of gases from TRD, 4 - air bleed after compressor, 5 - the throttle plate, 6 - air collector/receptacle, 7 - ejector device, 8 - the supply of air to the cabin/compartment of tests.

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For an increase of the mass of air into system, can be included the ejector, but this is led to pitot loss.

For the prevention/warning of sweating or snow in the system of air supply, the air is dried. As moisture absorbers are applied silica gel, the alumogel and the activated bauxite. Fig. 85, shows the schematic of the drying device. During operation of shutter/valve

a, b, d, are closed and air passes through filters 5 and 7 and drying sections 6 into channel. After the saturation of dryer by moisture is produced its regeneration, for which shutter/valve b, c, e they are closed. During the regeneration of moisture absorber, the air is drawn in through inlet cascades 4 by fan 3, it is preheated with the aid of the combustion of fuel/propellant in the chambers, it passes through drying sections 6 and is abstract/removed through shutter/valve d. Cooler 2 in this case is turned off.

In accordance with the character of the leading tests entering engine air it is necessary either to heat or to cool.

Large quantities of air are preheated by the combustion of fuel/propellant or with the aid of the heat accumulators. In the first case the air is contaminated by combustion products, which is reflected in the work of the tested object. Fig. 86, shows the part of the heat accumulator, which is of steel matrix/dies the total weight of 36 t, heated by electric heaters by the power of 1500 kW. Along the length the storage battery/accumulator is divided on three sections; the established/installed between them shutter/valves make it possible to support with the aid of pneumatic regulators the assigned outlet temperature from each section.

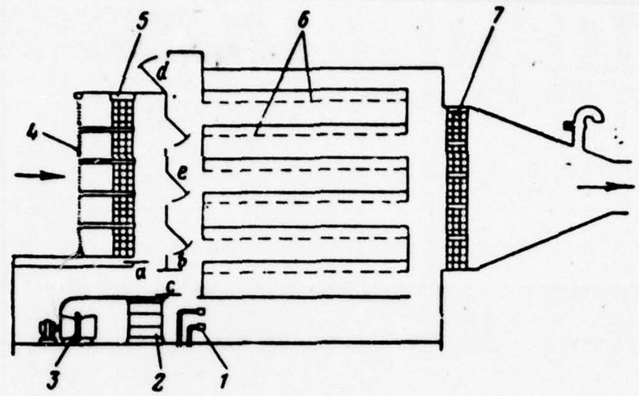

Fig. 85. Schematic of air-dryer. 1 - preheating torches, 2 - the coolant of air, 3 - fan, 4 - inlet cascade, 5 - primary filter, 6 - drying sections, 7 - secondary filter.

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Special thermostats limit the maximum permissible temperature of matrix/dies.

Electrical preheating during the full-scale tests of engines is unprofitable due to the high expenditures of electric power (heating 50 kg/s of air on 540° it requires more than 25 altitudes kW). The majority of stands of full-scale VRD work with the preheaters in

which is burned the hydrocarbon fuel (gas, kerosene, petroleum).

For the decrease in the temperature of air, which enters the engine are applied centrifugal expanders, which are a turbine whose power is absorbed by brakes. The role of brake usually fulfills the centrifugal impeller, draw-in air from the atmosphere. For cooling of air, are utilized also freon refrigerators. In this case the air is cooled in the heat exchanger through which circulate the vapors of Freon. The pressure of the entering the engine air is regulated with the aid of throttle/chokes and bypasses.

The size/dimensions of air-supply main lines must be sufficient for the transmission of calculated quantities of air with the permissible losses of pressure.

The serious problem of the design of the air duct is its adaptation to a wide range of the air flow rates. Virtually it is not possible to rapidly change pressure and temperature of air at the low consumption in the conduit/manifolds, designed to considerably larger consumption. To a considerable degree this is related to air heaters. Hence follows the conclusion that the propulsion test facilities must have several feed systems of air from receivers or compressor station.

Exhaust system.

For decompression of gases for the purpose of the imitation of high-altitude conditions on exhaust the testing units equip with the system of precooling and suction of gases. Gases can be drawn off with the aid of the exhausters, given into action by electric motors or turbines.

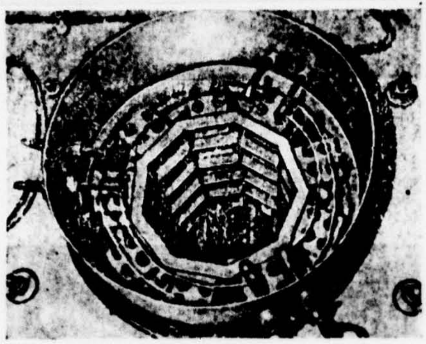

Fig. 86. Part of heat accumulator with matrix/dies.

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It is possible to apply the exhausters, carried out on the base of series turbojet engines. In some cases are utilized also the multistage steam ejectors, fed by vapor from the storage battery/accumulators, loaded from boilers.

Cooling exhaust gases can be reached in heat exchangers (the cooling agent - water), or by injection of water in the flow of gases. System with injection simpler and is more advisable, since reduces to the minimum explosion hazard, possible with starting/launching or hitch of the tested engine. Sometimes are applied simultaneously both methods.

Fuel system.

The fuel systems of laboratory are characterized by universality, great possibilities of the flow-rate control, pressure and temperature of fuel/propellant at the engine inlet, and also a large quantity of monitoring-measuring equipment. With the imitation of high-altitude conditions, are required two independent fuel systems. The fuel tank of the first system is furnished outside heatandpressure simulation chamber, the fuel tank of the second - within heatandpressure simulation chamber, which makes it possible to change pressure and temperature of fuel/propellant in tank.

Support systems.

In the number of the auxiliary devices of laboratories, must be located the pumping plants, which ensure the supply of large quantities of water for cooling of installations, exhaust gases, fuel/propellants, etc. The existing pumping plants with high-altitude

laboratories for the studies of jet engines provide water supply to 25 m^3/min. With large consumption the water is cooled with the aid of saltpans or in basins, whence it returns to laboratory.

Large value for laboratories have the distribution systems of electric power. In electrical equipment of laboratories, enter the electric motors of alternating current, dynamotors, direct-current generators, current transformers, the frequency converters, etc. The total power of expendable electric power is measured in tens of thousands of kilowatts. The electric system of laboratories must provide the connection of the instruments of direct and alternating current with different voltages.

Complexity of investigations, unwieldiness of installations, requirement for safety engineering and large number of measurements (reaching several hundreds), conducted during experiments during brief time, cause the need for remote control, observation and recording the parameters.

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Observation is conducted directly through special windows or with the aid of television equipment. Recording it is expedient to carry out by the auto/self-squeaking instruments.

Readings can automatically be transferred to electric calculators, which analyze results. Such systems can consider calibration and provide the current readout of tests. Entire cycle of measurements and their treatment in indicated conditions occupies approximately 1 min. For the installations of short-term action this period is great. On them successfully are utilized automatic measuring systems with the accumulation of the obtained data. In such systems the introduced readings are converted into the digital signals, record/written on magnetic tape. After completion of tests, the tape is passed through the appropriate converter, giving punched cards which then are processed in calculators.

Fig. 87, shows one of the possible schematics of control of tests and recording measurements. Readings are transferred on wire/conductors to instrument room. In instrument room the signals are coded and all information is transferred to control location, and then heads for memory unit. After analysis in electronic computer, the data are recorded or are record/written graphically by automatic methods. If necessary, some data can be examined and are automatically recorded separately during tests for purposes of control.

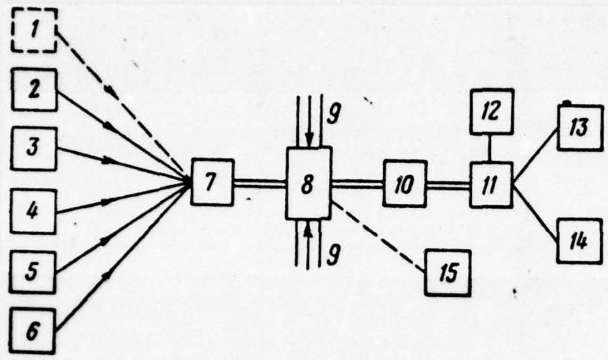

Fig. 87. Block diagram of control. 1 - analog-digital converter for transfer operations; the converters of the measurement: 2 - pressures; 3 - temperature; 4 - number of revolutions; 5 - fuel consumption; 6 - thrust/rod; 7 - block of processing; 8 - junction box; 9 - input/introduction of numerical data from other cells; 10 - memory unit; 11 - computer; 12 - post of manual control; 13 - tabulator; 14 - automatic instrument for graphing; 15 - electromechanical indicator of data.

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2. Laboratories for the altitude tests of engines.

Taking the high-altitude and speed characteristics of engine on the earth/ground requires special complex equipment and the specially fitted out for these purposes locations - the high-altitude laboratories in which are solved the following problems:

1) taking the altitude-speed engine characteristics;

2) the determination of the range of stalled conditions and the selection of the mode/conditions of operation;

3) testing of startability of engine at different height/altitudes at different flight speeds;

4) combustion research under high-altitude conditions;

5) the determination of the effect of climatic conditions for the work of engines, etc.

In order to reproduce on the stand of the condition of the operation in flight, it is necessary to ensure the possibility of pressure adjustment, temperature and air humidity, which enters the engine and the heatandpressure simulation chamber and exhaust pressures. During performance testing and calibration taking into account external resistance, it is necessary to create the

appropriate conditions of the flow about the engine.

Schematic of one of the high-altitude installations is depicted on Fig. 88. Unit makes it possible to conduct an investigation of operating conditions of full-scale engine and processes of burning in the separate chambers to altitude H = 15 km.

Air, in passing by through the filter, it enters two-stage centrifugal compressor 1, given into action by electric motor.

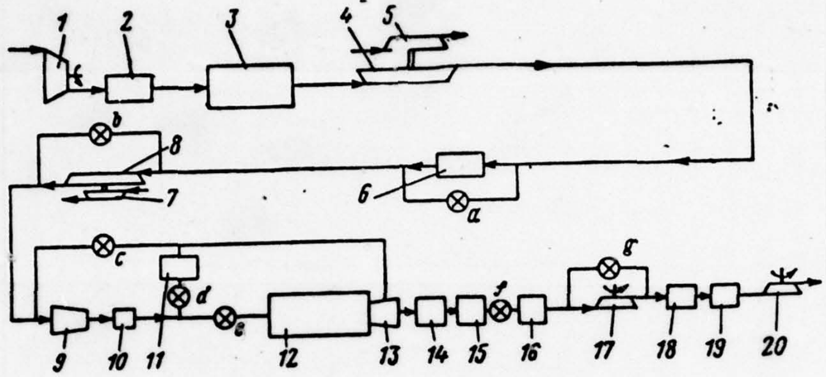

Fig. 88. Diagram of high-altitude installation. 1 - compressor, 2, 6, 14, 18 - heat exchangers, 3 - air-dryer, 4, 8 - turboexpanders, 5, 7 - air brakes, 9 - metering nozzles, 10 - air heater, 11 - stand of combustion chambers, 12 - heatandpressure simulation chamber, 13 - diffuser, 15 - preheater, 16, 19 - injection coolants, 17, 20 - exhausters, a, b, c, d, e, f, g - valve/gates and valves.

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Between cascade/stages and after compressor are establish/installed the coolers. The temperature of air at the output/yield of compressor can be order 300°C, pressure 5.6 atm(abs.), the air flow rate is constant, equal to 3.17 kg/s and is regulated by bypass valves. From compressor the air enters tubular heat exchanger 2.

Further air passes into air-dryer 3, which consists of two pairs of the standard sections, working on activated oxide of aluminum and included alternately. After air-dryer the air enters turboexpander 4 whose power is absorbed by air brake 5 (by centrifugal compressor). At output/yield from heat exchanger 6, temperature of air grow/rises. Operating temperature of the latter is reached with the aid of second turboexpander 8, in which the temperature can be lowered/reduced to -100°C, and pressure - approximately to 1.05 atm. With the aid of bypass valve b, is establish/installed the necessary temperature. After turboexpander the air branches. The part of it, that goes to the test bench, enters the group of metering nozzles 9, connected in parallel and having different diameter, which makes it possible to carry out precise measurements over a wide range of the air flow rates.

After metering nozzles is arrange/located electrical air heater 10, equipped with lamellar thermostat. In passing by through the preheater, air heads either for stand of combustion chambers 11 or into heatandpressure simulation chamber 12.

Heatandpressure simulation chamber has inner diameter approximately 4 m and length 12 m. From the entry of air, the chamber is carried out dismountable/release, which is necessary for unit and taking tested engine. Access to it in the interval/gaps between tests

it is provided through the hatch, arrange/located in side wall. The chamber is covered outside with thermal insulation layer. Within the chamber the air will be fed directly to the engine inlet.

The thrust/rod of turbojet engines is determined either by calculation on the basis of the measurement of the parameters of exhaust gases or by dynamometric device. The power of turboprop engines is absorbed by the hydraulic brake, establish/installed within the chamber.

Fuel/propellant is fed from the tank, arrange/located within heatandpressure simulation chamber, through a series of the heat exchangers, which make it possible to regulate its temperature. Fuel tank is found whose value changes depending on the degree of height in the chamber. The jet nozzle of engine is introduced into diffuser 13, which makes it possible to increase the height of the chamber. Diffuser is cooled by water just as entering it exhaust pipe of stand of combustion chambers.

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From diffuser the gases enter tubular water-cooled heat exchanger 14, in which they if necessary can be cooled, pass into preheater 15 and through valve f, employee for the control of height,

into injection coolant 16, the being series of the injectors, injection water into the flow of gases. Two Last/latter aggregate/units support the parameters of gas at the entry into exhauster 17 in accordance with his operating point.

Preheater 15 is necessary in the case of end of burning in engine chambers when the temperature of gases at the entry into exhauster proves to be too low. So that the unburned fuel/propellant would not be ignited in preheater, it was made tubular and with preheating hot water. After exhauster the temperature of gases again grow/rises approximately by 200°C; therefore before entrance in second exhauster 20, gases again are cooled in heat exchanger 18 and injection coolant 19.

Design conditions of exhauster must be supported by appropriate pressure adjustment, inlet temperature and of the air flow rate. Otherwise the exhauster can leave to stalled condition or to the inadmissible number of revolutions. The weight flow rate of air in exhauster 20 is more than in exhauster 17, because of air suction from the environment into injection coolant 19. Pressure at the entry into exhausters is supported by constant with the aid of bypass valves. The drive of exhausters is realize/accomplished through multipliers from electric motors.

If necessary for the supply of a large quantity of air into the tested engine, pressure regulator automatically closes valve c and is open/disclosed valve f how it prevents a change in the mode/conditions of work of exhausters. During decrease in the air flow rate, bypass valve c is open/disclosed, and bypass valve g of exhauster works as safety. The necessary "height/altitude" is reached by the flow-rate control of air by valve c pressure by valve f. The necessary temperature of air is reached with the aid of bypass valve b of the second expansion turbine.

Special difficulty represents the altitude test of turboprop engine with propellers. Fig. 89, shows the schematic of the stand, which makes it possible to experience/test TVD both under terrestrial and under high-altitude conditions. In the latter case the air to the engine inlet will be fed from the compressor along tubes 2. Air for the load of screw/propellers is take/selected from the atmosphere through the device for silencing 1 and is fed to screw/propellers with the aid of adjustable nozzle 5. The diameter of the latter can change over wide limits from 2.5 to 6.0 m. This control must remove pulsations of propeller-blades tip. The nozzle can be misaligned forward and back depending on length of TVD. Exhaust gases of engine are cooled in coolants and are drawn off by exhausters. Jet from screw/propeller passes mufflers 3.

Fig. 90, depicts the schematic of the arrangement of basic constructions and devices of high-altitude experimental testing laboratory turbojet and turboprop engines.

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In laboratory can be created the conditions, which correspond high speeds and flight altitudes (approximately M = 2.5 and H = 21,000 m). For the control of the indicated parameters in the necessary range, is required to ensure air pressure at the engine inlet from 0.07 to 3.8 kg/cm² and temperature from -90 to +190°C, but the pressure of the which surrounds engine air from atmospheric to 0.035 kg/cm², which corresponds to the maximum base altitude.

The high-altitude units of laboratories require large energy powers; thus, for instance, only electric motors of the drive of all compressors can have power on the order of 30,000 kW.

Laboratory has the intake department/separation in which the air is led to the appropriate parameters, and output section. Both these department/separations are placed in separate housings.

Section for tests under conditions of high altitudes consists of two chambers. The first of these chambers is the air scoop into which

the air enters at required temperature and a pressure. Air scoop is equipped with the special guide vanes and airfoil/profiles for flattening of flux and with equipment for the measurement of temperature and pressure. In the second chamber on the assemblies, equipped with sensors for the measurement of thrust force with the aid of special weights, is establish/installed the engine. Experimental section is equipped by safety valves.

Testing of PVRD [ramjet engine] and their assemblies the units, which make it possible to imitate flight speeds with Mach number = 2-3, is connected with very large energy consumption. In connection with this frequently they resort to producing of the wind tunnels of supersonic speeds of periodic action. Are possible and are applied three types of the supersonic installations of the short-term action whose difference is in the method of the organization of supersonic flow.

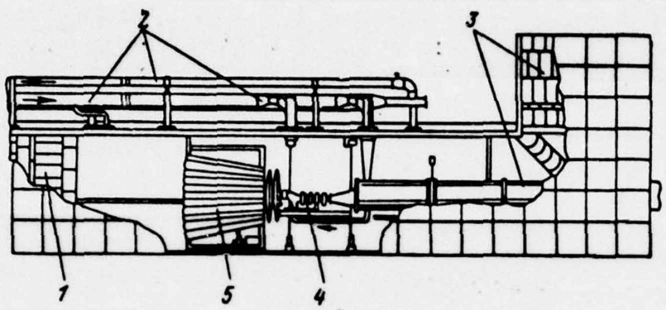

Fig. 89. Schematic of test bench of TVD. 1 - device for the silencing of air-in, 2 - the supply of air from compressor, 3 - the mufflers of exhaust and exhaust manifold, 4 - TVD, establish/installed for altitude tests, 5 - the adjustable air nozzle.

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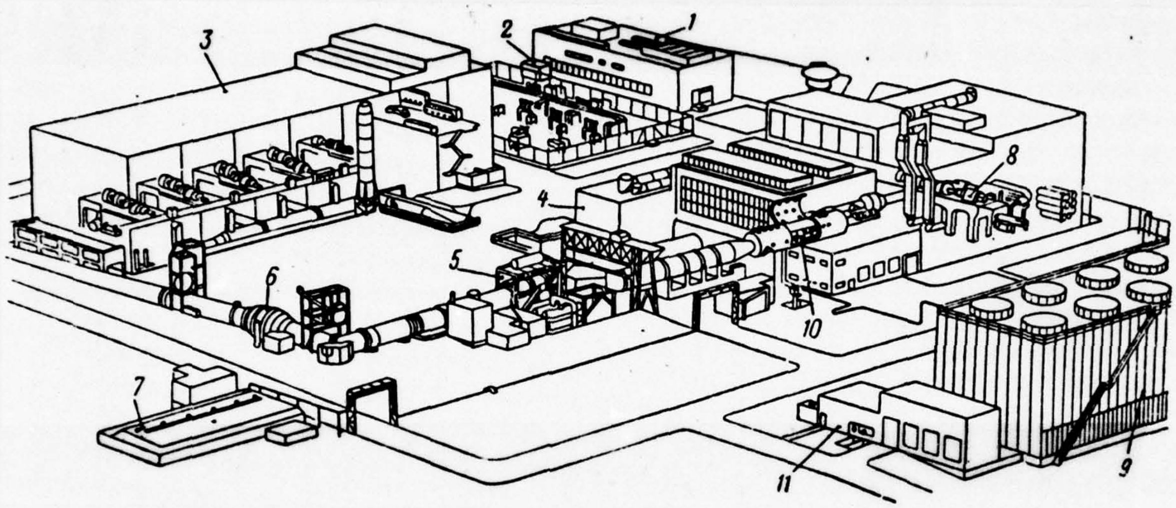

Fig. 90. Schematic of arrangement of basic constructions and devices of high-altitude laboratory. 1 - administrative housing, 2 - substation, 3 - the housing of exhausters (output section), 4 - the building of test benches of compressors, 5 - primary cooler, 6 - the aftercooler, 7 - fuel reservoir, 8 - compressor station (intake department/separation), 9 are a saltpan, 10 - pressure chamber, 11 - pump.

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In the first type the bottles are filled with the compressed to several hundreds of atmosphere air which is produced in the form of the supersonic jet for the tested objective (engine, model airplane, projectile etc.).

In the second type in receiver, is created the vacuum. Air from the environment flows into receiver and in airflow tests engine or another object.

The third type of unit is combination the the first two.

The units of the examined schematics do not require powerful compressors, but to carry out experiments on them is difficult due to the small time interval, during which the parameters of jet are supported by constant/invariable.

During tests of PVRD, it is very important to explain the effect of angles of attack on the engine operation. For the imitation of a

change in the angles of attack at units, it is usually accepted to change the slope/inclination of the axle/axis not of engine, but the blowing off/out nozzle. A shortcoming in this unit is not circumvential nature to change the blowing off/out nozzle during taking of characteristics of engine according to Mach number.

Fig. 91, gives the schematic of the working section of supersonic pressure chamber with adjustable nozzle. The supersonic nozzle of rectangular cross section is regulated with the aid of two flexible walls which can be moved between fixed walls.

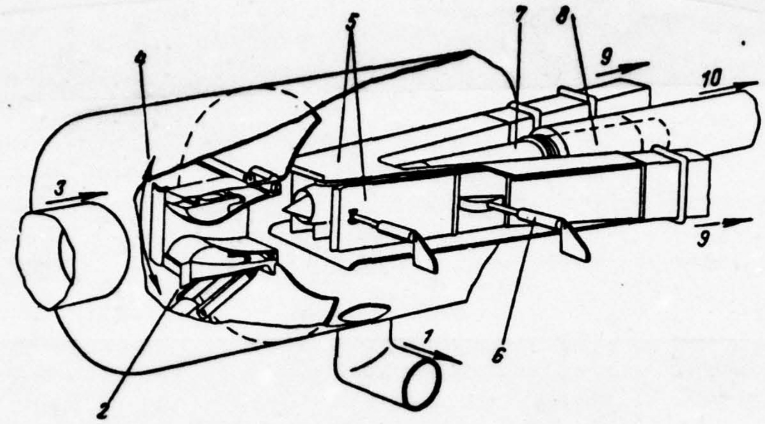

Fig. 91. Schematic of the test section of the supersonic unit. 1 - branch connection to exhauster, 2 - the adjustable supersonic nozzle, 3 - the entry of air of the assigned parameters, 4 - angle of rotation for the imitation of downwash, 5 - the expanding ducts of alternating/variable geometry for the blowing off/out air, 6 - plungers for displacing the walls of channel, 7 - engine, 8 - the exhaust duct, water-cooled, 9 - to subsonic diffuser and the coolant of blowing off air, 10 - to coolant of exhaust gases of engine.

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Diffuser for the air, which blows off/out engine, also has adjustable side walls. The imitation of downwash at entry is reached by the

rotation of entire nozzle. Pressure in the section of the chamber, in which are placed the engine and diffuser, is supported in accordance with assigned flight altitude.

Basic control occurs by changing nozzle throat. Air bleeding and control of the cross section of diffuser are produced automatically in accordance with high-altitude pressure in the chamber. Control system must prevent/warn the emergence of surge in grid/network.

During the design of the feed systems of air in units with free blowout there is special interest in the ratio of the area of the blowing off/out nozzle F_c to the area of the intake part of the engine $F_{\text{дв}}$. The graph of the recommended relations $F_c/F_{\text{дв}}$ for axisymmetric puffed with the different Mach numbers was given in Fig. 92.

3. Stands of rotodynamic machines.

Investigations and the finishing of compressors and turbines occupy large place in works on creation of VRD. In contemporary jet engines are used extensively the multistage axial-flow compressors and the turbines, basic cell/element of which is airfoil cascade. The

correct selection of grid/cascade will ensure an improvement in the characteristics of rotodynamic machine and increase its efficiency. It is logical; therefore considerable attention is given to the study of grid/cascades.

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TESTS OF JET ENGINES,(U)

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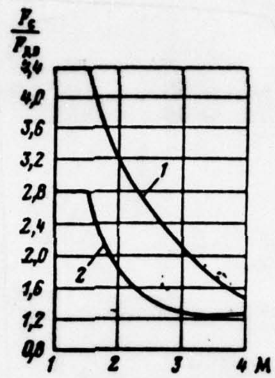

Fig. 92. The size/dimensions of those who blow off/out it puffed, necessary for the imitation of the conditions of flow at the entry in PVRD. 1 - the maximum sizes of nozzle at high angles of attack and during subcritical mode/conditions, 2 - the minimal sizes of nozzle at low angles of attack and during supercritical mode/conditions.

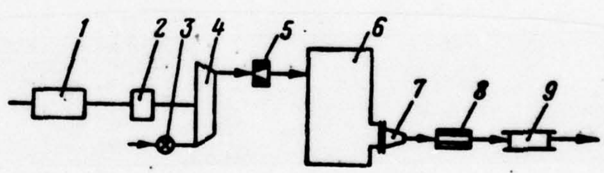

Fig. 93. Schematic diagram of setting for performance testing and calibration of grid/cascades. 1 - electric motor, 2 - multiplier, 3 - throttle/choke, 4 - compressor, 5 - metering nozzle, 6 - receiver, 7 - nozzle, 8 - stator blades, 9 - the test section of the unit with grid/cascade.

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Schematic diagram of setting for determining the characteristics of the grid/cascades is shown in Fig. 93. Air from compressor through the receiver, the nozzle and guide vane enters the test section of the installation in which over wide limits it is possible to change: angle of attack, the angle of setting airfoil/profiles and lattice spacing.

Fig. 94 shows one of the versions of the design concept of the test section of the setting. Angle of attack can be changed with two rotary shaped insets 4. Insets form the supplying section in which can be establish/installed the grid/cascade of guide plates 2, that ensures better flattening of flux. The assigned magnitude of α_0 is controlled on dial/limb.

The pressure field and velocities before and after airfoil cascade 1 being investigated is remove/taken by sounding (pneumatic method). It is necessary to note that the indicated method is very labor-consuming, requires the high expenditure of time for conducting experiments, but during their careful execution it provides

sufficient accuracy of measurements.

Below method of the weighing of reaction force in question makes it possible to obtain the integral characteristics of grid/cascades with the considerably smaller expenditure of time for the production of experiments. The high productivity of method makes it possible to easily obtain a comparative evaluation of grid/cascades, which are distinguished by the form of airfoil/profile, by the geometric and regime parameters.

Fig. 95, shows the installation diagram for the weighing of the reaction force, which makes it possible to also determine its circular/neighboring and axial components.

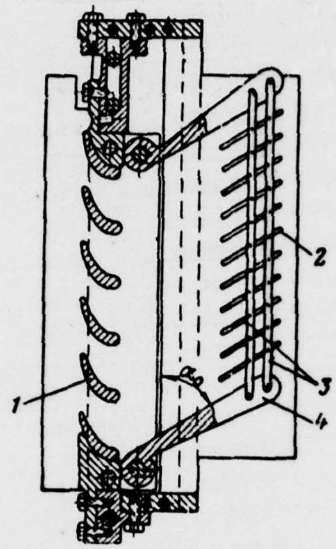

Fig. 94. Design concept of the test section of the setting for determining air foil data. 1 - the grid/cascade being investigated, 2 - directing plates, 3 - thrust/rod, 4 - the rotary shaped insets.

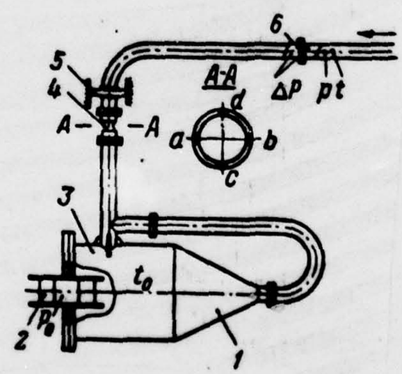

Fig. 95. Installation diagram for determining the reaction force of grid/cascade. 1 - diffuser, 2 - grid/cascade, 3 - receiver, 4 -

flexible cell/element, 5 - support, 6 - metering nozzle.

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Air from the compressor through metering nozzle 6 and diffuser 1 heads for receiver 3 in which is establish/installed grid/cascade 2 being investigated. Receiver with grid/cascade is fastened on the vertical section of air duct, which has in upper part fixed support 5.

The tested grid/cascade is establish/installed in horizontal plane. Reaction force is received by flexible cell/element 4, carried out in the form of the section of conduit/manifold with fine/thin wall. On its surface along two mutually perpendicular axle/axes ab and CD, are stuck four strain gauges (cross section AA). the presence of two sensors on one axle/axis raises the sensitivity of bridge and contributes to thermocompensation. Two Sensors, dead in line, are formed two bridge arms, the others of two arms are removed to the special slide wire, which makes it possible to conduct the calibration of bridge.

With the aid of sensors, arrange/located on the axis ab, they measure the axial component R_a of reaction force R, while with the

aid of the sensors, located on the axis CD - the circular/neighboring component R_u of reaction force.

The knowledge of the real consumption of the air $G_в$, measured with the aid of metering nozzle, and reaction force R,

$$R=\sqrt{R_a^2+R_u^2}, \quad (108)$$

components of which R_a and R_u are determined by the means of strain-measuring weights, it makes it possible to determine average outlet velocity

$$c_1=\frac{gR}{G_в}, \quad (109)$$

the velocity coefficients and consumption

$$\varphi=\frac{c_1}{c_{1т}} \quad (110)$$

and

$$\mu=\frac{G_в}{G_{в.т}}, \quad (111)$$

and also the mean angle of flow at the output/yield

$$\alpha_1=\operatorname{arc\,tg}\frac{R_a}{R_u}. \quad (112)$$

The value of velocity $c_{1т}$ and of consumption $G_{в.т}$ is located through common gas-dynamic formulas.

The examined setting makes it possible to determine effect on the characteristics of the grid/cascades only of Mach number.

Fig. 96, gives the installation diagram for the blasting of grid/cascades, which makes it possible to consider effect on the characteristics of Re number.

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In this case, it is possible to change Mach numbers and Re independently of each other, which is achieved by a change of the jump/drops in pressures and air density, which flows around grid/cascade in hermetically sealed during tests system. The results of such tests are utilized during the calculation of altitude performances of engines.

The entering from compressor 3 air is cooled in heat exchanger 4 and through nozzle 6 is fed to tested grid/cascade 7. The air flow rate is determined with the aid of metering nozzle 5. In setting is provided for a whole series of shutter/valves (valve/gates), necessary for control. Air density in the closed system of setting descends with the aid of vacuum pump 11.

Let us pass to the examination of installations for performance

testing and calibration of compressors and their step/stages.

Fig. 97, shows the schematic of stand of the step/stage of axial-flow compressor. By the appropriate change in the revolutions of electric motor, position of the throttle plates and thermal effect on air in heat exchanger and cooler it is possible to establish/install on the tested compressor stage mode/conditions with the different values of the flow rate of the air and parameters at entry. The schematic of stand of full-scale compressor is similar that which was described. Frequently the investigation of compressor is conducted directly in the system of engine. however, in this case the characteristic of compressor can be removed incompletely, and only in a comparatively narrow range.

Fig. 98, depicts the schematic of closed type vacuum system, which makes it possible to conduct tests with the same volumetric flow rate of air, as in actuality. The weight flow rate of air in this case will be less. In system enters the tested compressor, that throttles device, heat exchanger and air turbine, which returns the part of the power, spent on the drive of compressor.

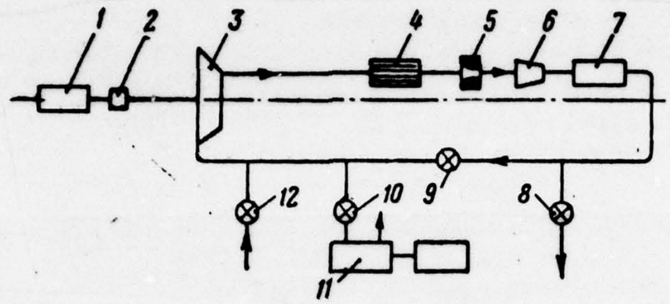

Fig. 96. the schematic diagram of setting for the blasting of grid/cascades. 1 - electric motor, 2 - multiplier, 3 - compressor, 4 - heat exchanger, 5 - metering nozzle, 6 - nozzle, 7 - the grid/cascade being investigated, 8 - discharge valve, 9 - throttle/choke, 10 - the valve/gate of vacuum-pump, 11 - vacuum pump, 12 - inlet valve.

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As power plant can be used a powerful electric motor (as shown in schematic) or gas turbine.

The air, which fills setting, preliminarily is dried to avoid the icing of measuring meters in low-temperature mode/conditions. The mode/conditions of tests regulates by change in the revolutions,

quantity of abstract/removed heat, pressure at the entry into compressor and by throttling/choking. Temperature of air at the inlet into compressor can be changed over wide limits which is very important for the imitation of high-altitude and high-speed/velocity conditions during testing.

To apply in setting air turbine not is compulsory, since throttle/choke and heat exchanger make it possible to establish/install the necessary parameters. However, in this case appear considerable losses with the throttling/choking of air, and heat exchangers are very bulky.

Turbine performance are remove/taken with special settings.

The power of turbines is absorbed by hydraulic brake or the compressor (Fig. 99), draw-in air from the atmosphere. The power, consumed by air brake 3, is regulated by a change in the air flow rate by shutter/valve 1. As can be seen from schematic, into turbine 4 being investigated enter the gases from chamber 13.

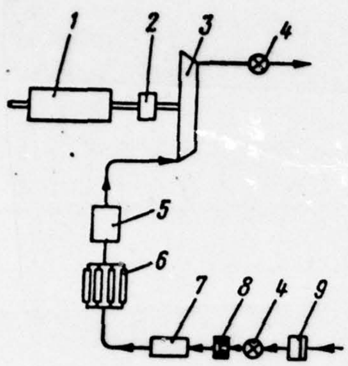

Fig. 97.

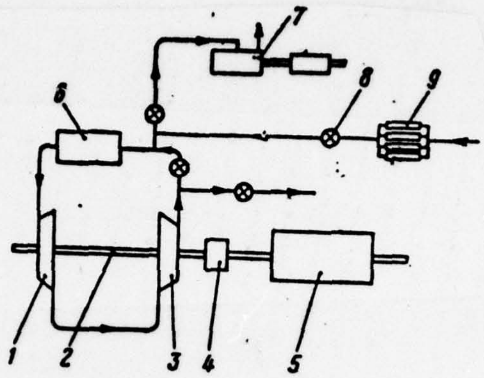

Fig 98

Fig. 97. Schematic of stand of compressor stage. 1 - electric motor, 2 - multiplier, 3 - compressor stage, 4 - the throttle plate, 5 - cooler, 6 - air-dryer, 7 - heat exchanger, 8 - measured diaphragm, 9 - air filter.

Fig. 98. Schematic of closed type vacuum system. 1 - air turbine, 2 - spring, 3 - compressor, 4 - multiplier, 5 - electric motor, 6 - heat exchanger, 7 - vacuum pump with electric motor, 8 - the throttle plate, 9 - air dryer.

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The power of turbine, equal to the power of compressor, is determined

from the formula

$$N_т \approx N_к = \frac{G_в c_p (T_2^* - T_1^*)}{75A}, \quad (113)$$

where T^*_1 is temperature of stagnation of air intake; T^*_2 is temperature of stagnation of air at output/yield from air brake 3; $G_в$ is air flow rate through air brake; c_p is heat capacity of the air.

In the setting in question the turbine and air brake are regulated autonomously, which makes it possible to change the mode/conditions of work of turbine over a wide range. More accurate results give the tests of the turbines whose power is absorbed by hydraulic brake.

4. Stands of combustion chambers.

In view of the fact that the questions, connected with aerodynamics of the chamber and processes of burning in it, are extremely complex, the existing combustion chambers are improved, mainly, experimentally.

For a reduction/descent in the expenditures on the creation of the new chambers, it would be desirable pass from full-scale tests to

model, with the concluding tests on full-scale chambers. However, due to the difficulties of the simulation of the chamber, this "two-stage" procedure of their creation is not applied.

Fig. 100, shows the schematic of laboratory unit for combustion research. As can be seen from schematic, air into chamber 1 enters from the compressor station through heat exchanger 2, in which it is heated by the abstract/removed from the chamber gases.

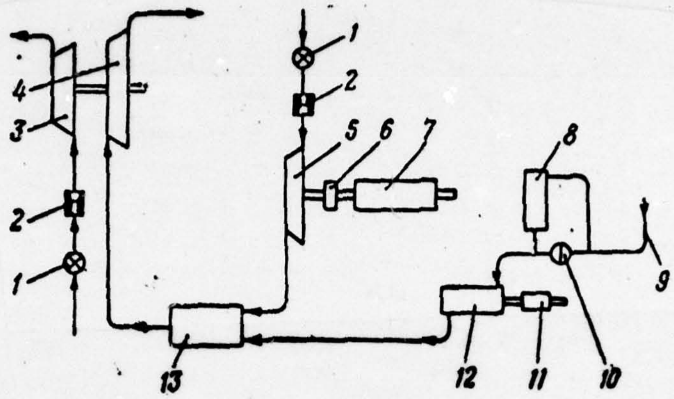

Fig. 99. Schematic of stand of turbines. 1 - the throttle plate, 2 - measured diaphragm, 3 - air brake, 4 - tested turbine, 5 - compressor, 6 - multiplier 7, 11 - electric motors, 8 - fuel meter, 9 - fuel line, 10 - valve/gate, 12 - fuel pump, 13 - combustion chamber.

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The presence of heat exchangers makes it possible to have at the entry into the combustion chamber the elevated temperature - characteristic for the modes of the chamber operation of combustion in flight at high velocities. Furthermore, the special suction system with coolant 4 makes it possible to obtain the low pressures at entry, which correspond to high-altitude conditions.

When conducting of the experimental tests of combustion chambers, essential attention is given to the determination of the combustion efficiency ξ, of the pressure recovery factor σ^* and of the uniformity of temperature field at chamber exit.

The combustion efficiency is defined as ratio of a quantity of heat, which was really/actually separated during burning Q_{π}. to the quantity of heat, conducted with fuel/propellant Q_{T}:

$$\xi=\frac{Q_{\pi}}{Q_{T}}. \qquad (114)$$

Value Q_{T} always can be determined by calculation, knowing the flow rate of fuel/propellant and its calorific value. considerable difficulty presents determination Q_{π}.

In principle Q_{π} it is possible to determine by the method of calorimetric measurement, by a direct change in temperature and composition of gases, and also by the gravimetric methods, based on the measurement of the recoil impulse of the escape/ensuing from the chamber gas jet. The enumerated methods of determination ξ automatically connect the losses through chamber walls in the environment.

The method of calorimetric measurement is very bulky, since it requires the creation of large colorimeter for determining a quantity of heat, isolated by the cooled in calcrimeter gases, coming out from the chamber.

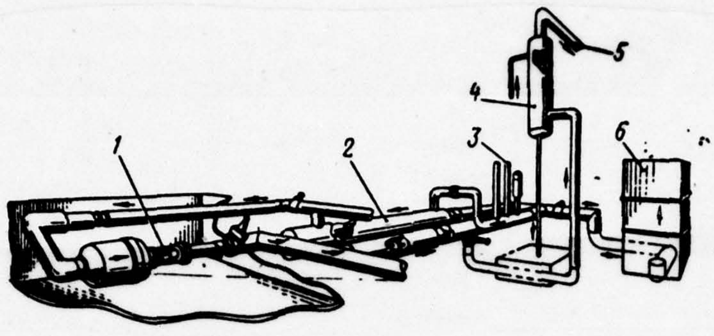

Fig. 100. Installation diagram for combustion research. 1 - the tested combustion chamber, 2 - heat exchanger, 3 - air supply, 4 - water cooler of gases, 5 - high-altitude exhaust system, 6 - exhaust silencer in the atmosphere (terrestrial conditions).

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It is necessary to note that the flow at combustion chamber exit is nonuniform both according to the temperature, density and velocities and in composition of gases. In connection with this the sample/test of gases they take/select from several points of cross section, and averaged-mass value ξ is determined from the expression

$$\xi = \frac{\sum_{1}^{n} G_{\text{г}\,i} c_{pi} \Delta t_i}{Q_{\text{т}}}, \tag{115}$$

where $G_{\text{г}\,i}$ is a gas flow through the appropriate section; c_{pi} is

average heat capacity of gases on section; $\Delta t_i = T^*_{3i} - T^*_2$ - the preheating of gases on section 2-3i.

Considerably smaller labor consumption possesses the gravimetric method, i.e., the method of the measurement of reacting force, which escape/ensues from the chamber of gas jet. By this method is obtained immediately averaged-mass value ξ without the need for the tedious measurements of loose parts of the flow.

For determining the pressure recovery factor of combustion chamber

$$\sigma^* = \frac{p^*_3}{p^*_2} \qquad (116)$$

it is necessary to know the total pressure at the entry into chamber p^*_2 and at output/yield from it p^*_3. The total pressures in cross sections also do not remain constants. Therefore one should apply the formula

$$\sigma^* = \frac{\sum_1^n G_{\text{r}\,i} p^*_{3i}}{\sum_1^n G_{\text{B}\,i} p^*_{2i}} \frac{G_{\text{B}}}{G_{\text{r}}}, \qquad (117)$$

giving averaged-mass value σ^*. In this formula $G_{\text{r}\,i}, G_{\text{B}\,i}$ is flow rate of gases and air through section i; p^*_{3i}, p^*_{2i} - the total pressure on sections 3i, 2i; $G_{\text{B}}, G_{\text{r}}$ are a flow of air and gases through the chamber.

Complete pressure at the different points of the cross section being investigated is measured by total-head tube with coordinate spacer apparatus or combs. Receivers on the comb of complete pressure are furnished so that they would be located in the middle of the equivalent areas to which broken this cross section. This arrangement of receivers makes it possible to determine the average value of pressure. The high temperatures of gases at chamber exit require the application of the cooled or manufactured from heat-resistant materials sensors.

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Fig. 101, gives the schematic diagram of stand model combustion chambers under terrestrial conditions. In this setting used special device for the measurement of reacting force of the escape/ensuing from the chamber gas jet.

Trap 1 (Fig. 102), suspend/hung cantilever from rod 2, rigidly attached in fixed bushing 3, is moved under the action of the flow, which enters it from the chamber. Rod undergoes bending strain; on its parallel planes A and B, at equal distance from the axle/axis of trap, are stuck two identical wire strain gauges (extensometer), that are two arms of Wheatstone bridge.

Of these of two sensors, placed into identical temperature conditions, but the experience/testing different deformations (elongation and compression), provide thermocompensation, i.e., is removed the effect of a change in the ambient temperature and rod for readings, and double the sensitivity of bridge.

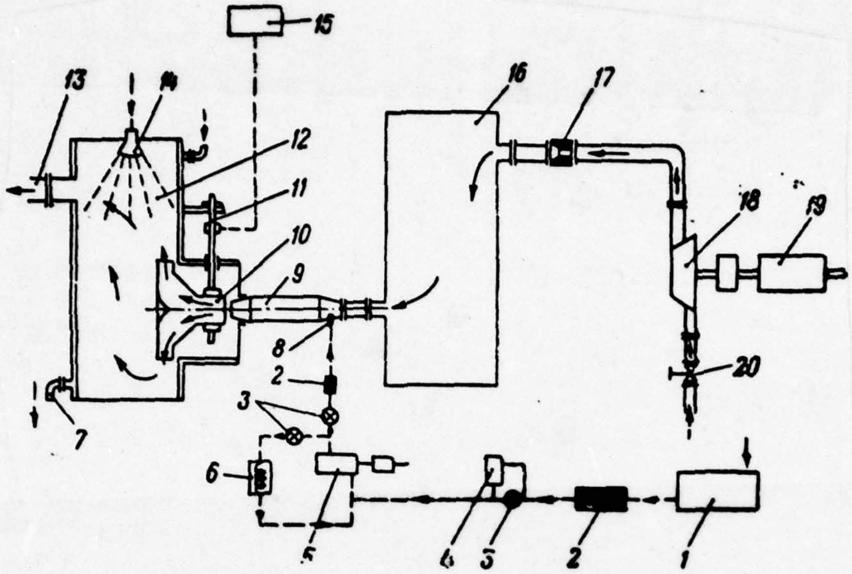

Fig. 101. Schematic diagram of stand model combustion chambers under terrestrial conditions. 1 - fuel tank, 2 - filters, 3 - valve tap/cranes, 4 - fuel meter, 5 - fuel pump, 6 - cooler, 7 - the drain of water from water jacket of exhaust receiver, 8 - injector, 9 - the chamber being investigated, 10 - trap for the weighing of the escape/ensuing gas jet, 11 - the rod of trap with the stuck on it extensometers, 12 - exhaust receiver, 13 - the ejection of gases in the atmosphere, 14 - souls's water, 15 - oscillograph, 16 - receiver, 17 - measured diaphragm, 18 - compressor, 19 - the drive of compressor 20 - the throttle plate.

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The most convenient schematic for the measurement of deformations is the schematic of the nonequilibrium bridge, working on alternating current. The changes of the current strength in bridge, caused by the deformation of rod, are proportional to the extent of the movement of trap along the axis of xx, i.e., are proportional to the value of thrust/rod and are record/fixed by oscillograph.

Fig. 103, shows the schematic of device with inductance pickup, employee also for the weighing of the discharging jet. The stock/rod of receiver 5 is attached on diaphragm/membranes 3 and 4. Under the effect of pressure of combustion products, the receiver is moved and changes clearance 6 between anchor 6, which sits on stock/rod, and the magnetic circuit of 7 induction transformer coil. Feed/supply of instrument is realize/accomplished by alternating current. The advantage of this instrument consists in the absence of the need for strengthening momentum/impulse/pulse even at its low values.

5. Stands of auxiliary units of aircraft engines.

Auxiliary engine accessories usually test in laboratories. Preliminarily at special settings check turbine starters, generators, fuel and oil pumps, different regulators and distributors, auxiliary gas turbines, injectors, devices for the drive of aircraft aggregate/units, etc.

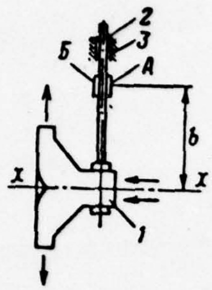

Fig. 102.

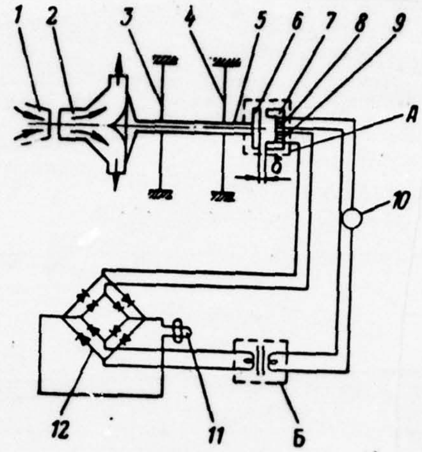

Fig. 103.

Fig. 102. Schematic of pulse meter with wire-type strain gauges. 1 - trap, ' - elastic rod, 3 - sleeve.

Fig. 103. Schematic of pulse meter with inductance pickup. 1 - nozzle, 2 - trap, 3, 4 - diaphragm/membrane, 5 - stock/rod, 6 - anchor, 7 - core, 8 - primary winding, 9 - secondary winding, 10 - audiofrequency oscillator, 11 - the tail of oscillograph, 12 - detector. A) the sensor unit, Б) the assembly of compensator.

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For the starting/launching of gas-turbine high-thrust engine, is required powerful starter. In this case frequently is applied the

turbine starter whose work is limited according to time and number of revolutions of disconnection. From the analysis of the specific character of work of turbine starter, it follows that accepted for the common gas turbine engines of the procedures of bench tests, that consists in the measurement of the parameters of engine in constant stabilized mode/conditions, does not make it possible to sufficiently accurately check work of starter unit before its setting to main engine. To approach the parameters of starting/launching of GTD [gas-turbine engine] the operational under bench conditions is possible only during the combination of the corresponding load of starter with the mode/conditions of continuous acceleration/dispersal.

Fig. 104, depicts the schematic of the stand for the dynamic tests of turbine starters, which makes it possible to observe close to operating condition of acceleration/dispersal during entire cycle of starting/launching and to change instantaneous power on the different revolutions of the power take-off. Stand has idle time by construction double-seat rotor and driving/homing spring, i.e., the elastic part of the torsion dynamometer. Of similar to the transmission main engine during starting/launching bench rotor creates inertial resistance to rotary acceleration and ventilation braking.

Rotor is the sitting on shaft steel disk-flywheel, on face of which, of a similar to the blade/vanes fan blower, are radially placed the blades of aerodynamic braking.

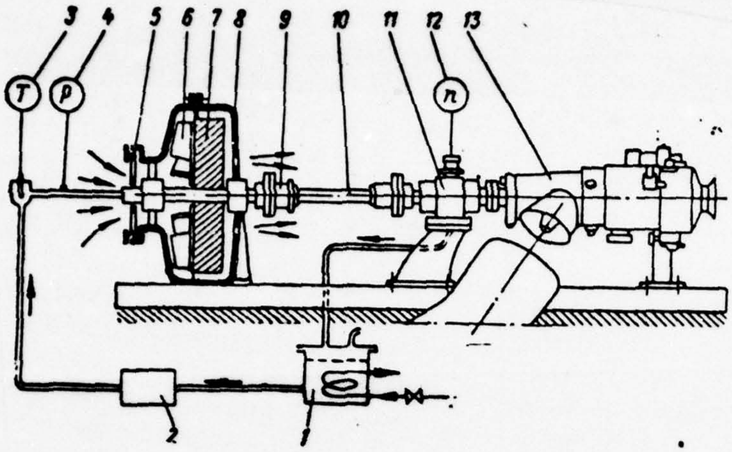

Fig. 104. Schematic of stand for the dynamic tests of turbine starters. 1 - oil tank with preheater, 2 - pump, 3 - thermometer, 4 - manometer, 5 - rotary blind, 6 - the blade of air brake, 7 - flywheel, 8 - the housing of air brake, 9 - the clutch of cohesion/coupling, 10 - the torsion shaft, 11 - oil valve, 12 - tachometer, 13 - turbine starter.

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In the housing of rotor, there are holes for entry and air outlet. Input windows can be throttled with special rotary blind.

Energy of turbine starter or starting mode/conditions partially is accumulated in flywheel, and it is partially absorbed by air brake. As meter $M_{кр}$ on the shaft of starter, is utilized hydraulic torsion dynamometer.

Considerable attention in laboratories is given to aggregate/unit tests of fuel system. As an example Fig. 105, gives the diagram of the hydraulic system of stand of fuel pumps. During their testing are checked capacities of pumps, control and effective range of the limiter of maximum revolutions, work of valves, common/general/total airtightness, etc.

In stand operation, the fuel/propellant from service tank 1 through check valve 2 by gravity/of one's own accord proceeds to booster pump 3. Further fuel/propellant under the pressure, created by booster pump, through low-pressure throttle valve 4 proceeds to one of rotameters 6 and then through low-pressure filter 7 and tap/crane 8 into tested pump 9. From pump the fuel/propellant through radiator 10 and partially through high-pressure throttle valve 13 enters back into service tank 1.

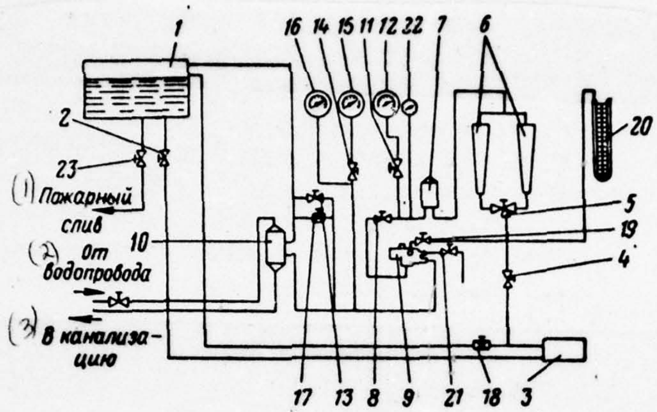

Fig. 105. the hydro-diagram of stand of fuel pumps. 1 - service tank, 2 - the stop cock, 3 - booster pump, 4 - low-pressure throttle valve, 5 - distributing cock, 6 - rotameters, 7 - low-pressure filter, 8 - the tap/crane of the entry into pump, 9 - the tested pump, 10 - radiator, 11 - the stop cock of manometer to 6 kg/cm², 12 - manometer to 6 kg/cm², 13 - high-pressure throttle valve, 14 - the tap/crane of manometer to 25 kg/cm², 15 - manometer to 25 kg/cm², 16 - manometer to 150 kg/cm², 17 - safety valve, 18 - the safety low-pressure valve, 19 - tap/crane, 20 - piezometer, 21 - tap/crane, 22 - telethermometer, 23 - the shut-off valve.

Key: (1). Fire drain. (2). From water pipe. (3). In channelization.

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The pressure of the fuel/propellant before rotameters regulates low-pressure by throttle valve 4. The pressure of the fuel/propellant before tap/crane 8 checks by manometer 12. Pressure at the entry into pump regulates by tap/crane 8, and they check by piezometer 20. Pressure at output/yield from pump regulates high-pressure by throttle valve 13, and they check by manometers 15 or 16 depending on the value of pressure. The temperature of fuel/propellant at the entry into the tested pump checks by telethermometer 22 and regulate by the consumption of the water through radiator 10.

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Chapter V.

EXPERIMENTAL STATIONS.

1. Classification of experimental stations and requirements for them.

At experimental stations aircraft engines are tested under terrestrial conditions. Station is the complex of construction constructions, equipped with the necessary equipment. Basic of them they are: boxes (cabin/compartment of tests), where are establish/installed the tested engines; the cabin/compartment of control, whence is conducted engine control and monitoring of their work, and technological locations for the arrangement/permutation of the power-supply systems of testing units.

To the auxiliary locations, necessary for operational provisions of the services of an entire station, they are related: exchange

point/item, shop of mechanic and electrician, department/separations of monitoring-measuring equipment, technical and administrative services, central fuel reservoir, etc.

The central fuel reservoir, arrange/located at a distance approximately 200 m of the building of station, is the determined quantity of the buried tanks, connected with each other. Fuel/propellant is fed to testing units mechanically (pumps), either under the pressure of dry air or the inert gas, forced into reservoirs.

Each testing unit is equipped with the single-purpose machine, which makes it possible to determine thrust level or torsional moment or each (during testing of TVD [ТВД - turboprop engine]) and by the systems: fuel, oil, starting/launching, air (compressorless VRD [ВРД - jet engine]), etc. At unit there is a control panel of engine with monitoring-measuring equipment. The enumerated equipment and systems provide test work and taking the necessary engine characteristics.

For the safety control and health and hygiene requirements for the construction of station, are equipped with the ventilation systems, noise suppression, fire-fighting protection, etc.

In the practice of tests, is found a use of a station of different types. Depending on the purpose of the tests of station, are divided into the experimental and series. By the type of the tested engine, are distinguished the stations for testing of compressorless VRD and station for testing compressor VRD, according to operating conditions - open and closed type station.

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When selecting the type of station the determining factors they are: the type of engine; the purpose of the tests; the designation/purpose of the enterprise in system of which is located the station; the type of the taken by station equipment; the character of the locality in which is arrange/located station, and its climatic conditions; the cost/value of experimental station.

Simplest are open type stations, whose tested engines are found on the open air and are shielded from atmospheric residue/settlings only by mounting fixtures, and control and observation of them is conducted from the cabin/compartments, arrange/located together. Such stations are very mobile and easily they can be moved from one area/site to another.

Are possible the cases, when it is expedient to forego test

bench for installation on it of engine, and to assemble the latter is direct on engine bed in aircraft and in this position to experience/test. This unit makes it possible to measure the actual thrust force of engine taking into account losses in suction and exhaust ducts of aircraft in all mode/conditions of work of TRD [ТРД - turbojet engine].

Open type stations are comparatively cheap, but they have the essential shortcomings: cannot be furnished them near the populated areas due to the absence of the special systems of noise suppression; the engine installation in the open air creates inconveniences for the personnel, which operates station, it impedes the conditions of the test work, etc. Open type experimental stations are applied in the report bases.

At the series aircraft engine-building plants, arrange/located in area of the large populated areas, are constructed only closed type experimental stations, in which the engine always is located indoor. Closed type stations provide the necessary conveniences to personnel, they make it possible to apply the highly efficient methods of noise suppression.

Depending on the construction of boxes and their arrangement relative to the cabin/compartments of control finds wide application

several forms of closed type experimental stations whose specific character is determined by tasks enumerated below and requirements.

Experimental station in series production must ensure: test work with the minimum expenditure of time for equipment and engine installation; the test conditions, which maximally approach operating conditions of engine; the supply of large quantities of filtered fuel/propellant; the cost-effectiveness/efficiency of tests; fire safety; noise suppression and good ventilation.

In chapter is given the basic information about closed type plant stations for testing the turboprop and turbojet engines.

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2. Boxes.

To boxes are presented the following requirements:

1) the suction part of the box must provide the feed/supply of the tested engine by the air, not clogged with dust and exhaust gases;

2) the suction part must be equipped with silencer;

3) box must provide the supply of air from the suction part to the worker in whom is located the tested engine;

4) exhaust casing of the box must be equipped with deflector of exhaust gases and with the silencer, which lowers the noise of the plume exhaust;

5) box must be equipped by doors for import and export of engines and by lifts;

6) the walls of box must be strong, that ensure the protection of the service personnel in the case of emergency and destruction of engine during tests.

Since boxes design/project universal, designed for testing of any type of gas turbine engine, the parameter, which determines the size/dimensions of unit, is the air flow rate through the engine and propellers, i.e., box it is designed for testing promising according to power of TVD.

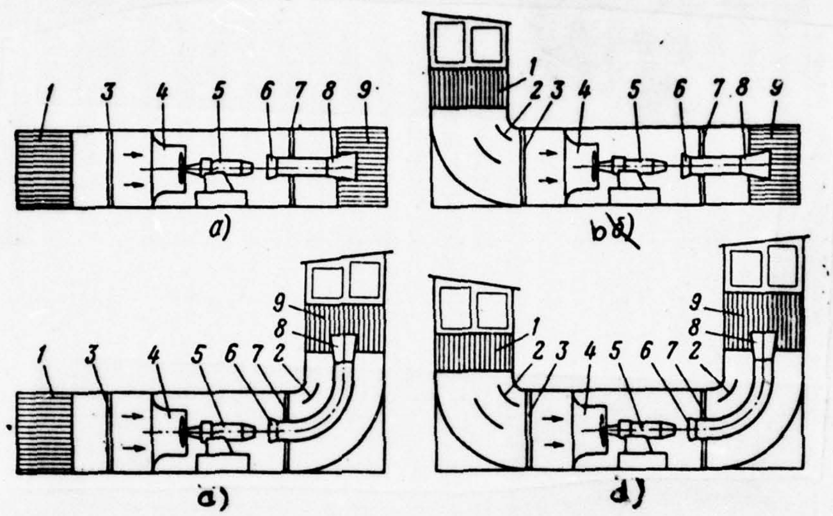

Fig. 106. Types of boxes: 1 - entry with sound suppressor, 2 - stator blades, 3 - entry gate, 4 - aerodynamic ring (for testing of TVD), 5 - engine, 6 - ejector, 7 - exit gate, 8 - output diffuser, 9 - output/yield with sound suppressor.

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In the practice of tests, find a use the boxes of four types, shown in Fig. 106. Most widely used of them are the boxes, presented

in Fig. 106a and b. The device of the silo at entry provides the feed/supply of engine by pure air. The horizontal ejection of combustion products makes it possible to successfully stun noise with the smaller expenditures of resources, than in the case of vertical ejection. From this viewpoint, the best conditions for noise suppression has the box with two horizontal shaft/mines, the very same has the best aerodynamic characteristics.

The selection of one or the other type of box is dictated by the conditions of the arrangement of plant, by type and the power of the tested engine, by the distance of experimental station from other objects of plant.

The test pit, as can be seen from Fig. 106, it consists of three basic parts: by the suction, worker (engine cabin/compartment) and exhaust. In engine cabin/compartment on special foundation, is mounted the machine tool to which is establish/installed the tested engine. If the engine is turboprop, then at the entry into engine cabin/compartment it is necessary to establish/install aerodynamic ring then so that propeller of engine would be located within it and their axle/axes coincided. The distance of propeller-blade tip from the wall of ring must be not less than 0.5-0.75 m, which provides a sufficient clearance for the prevention of the vibrations, excited by the motion of blade tips. Aerodynamic ring provides the best

conditions of the flow of air flow about the screw/propeller.

At output/yield from box, is establish/installed ejection pipe through which are removed the combustion products and because of which are decreased the temperature and the speed of exhaust gases (because of air suction). Ejection pipe and engine must register.

Fig. 107, depicts the box of testing unit. To box engine feed through special gate, and then with the aid of electric hoist establish/install to the test bench, attached on the special foundation, which absorbs the vibrations.

Vibration vibrations in foundation are partially absorbed by insulation pillow 2, made from cork board, the disinfected tree or felt. For isolation/insulation from lateral vibrations, there is an air space to 15-20 cm. The foundation of machine tool must be deeper than the foundation of the walls of building, which decreases their vibrations.

For the target/purpose of decrease in the fatigue voltage/stresses, caused by vibrations in the test section of the box, is recommended the constructing of the latter from the prestressed reinforced concrete with the thickness of walls approximately 200 mm.

Fig. 108, shows the equipment of engine on machine tool in the box before beginning of tests, while in Fig. 109, - established/installed on machine tool of TVD.

Is very important the correct selection of the velocities of air circulation in the suction part of the box and engine cabin/compartment, and also the rates of the air circulation and combustion products in exhaust casing.

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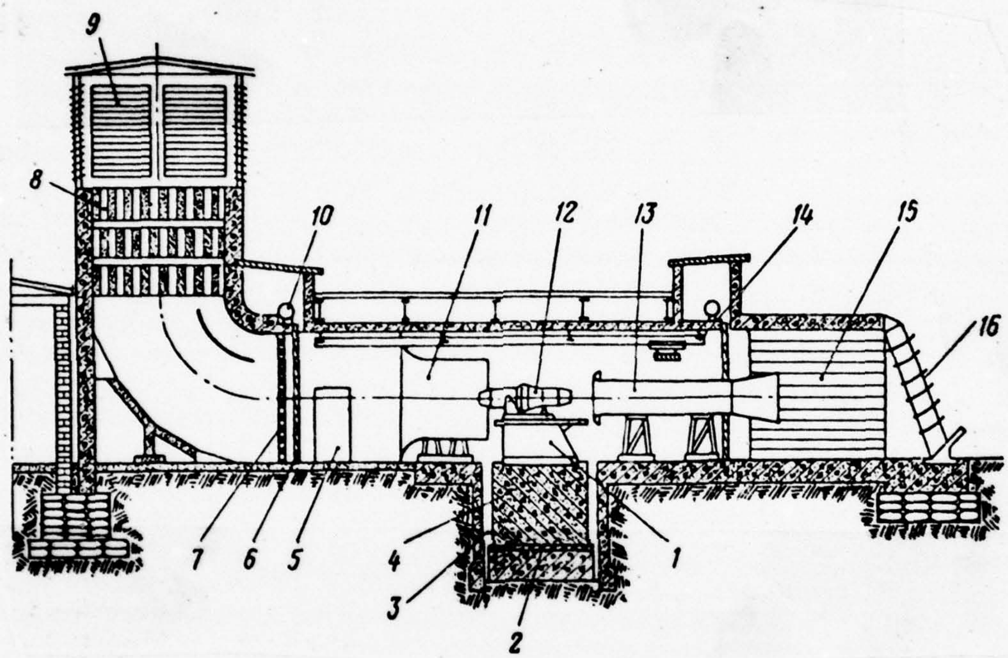

Fig. 107. Box of testing unit: 1 - machine tool, 2 - insulation pillow, 3 - air space, 4 - foundation, 5 - entry into box, 6 - louver, 7 - grid/cascade, 8 - sound suppressor at entry, 9 - entry of air, 10 - drive, 11 - aerodynamic ring, 12 - engine, 13 - ejector, 14 - electric hoist, 15 - sound suppressor at output/yield, 16 - recoil blades.

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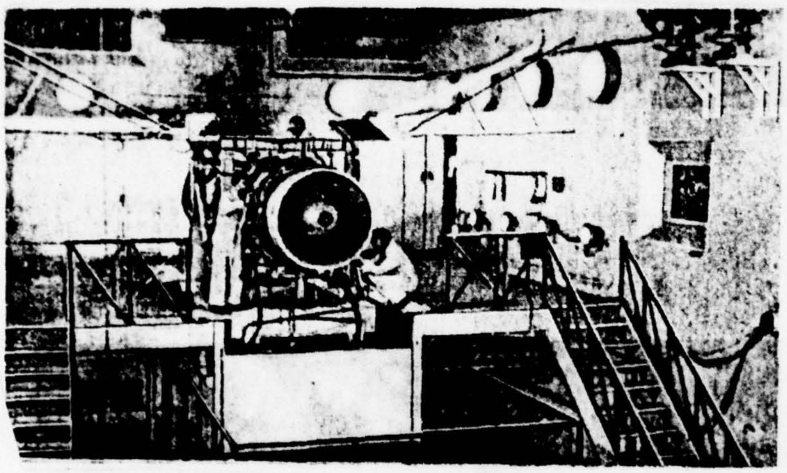

Fig. 108. Equipment of engine on machine tocl prior to tests.

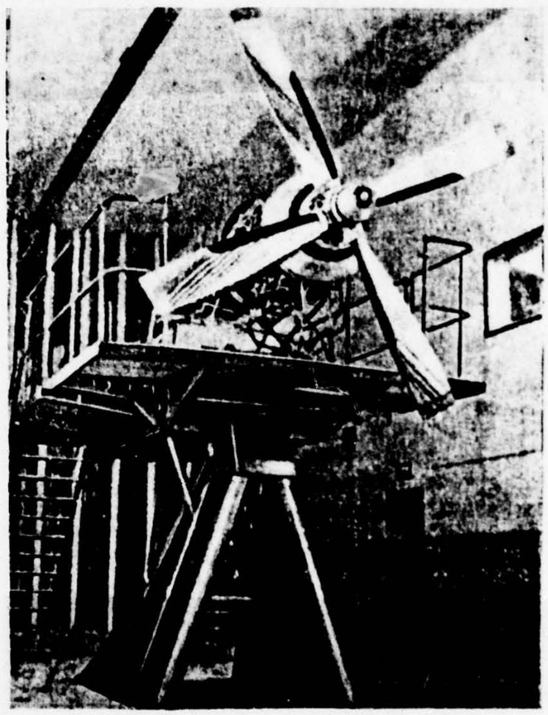

Fig. 109. Turboprop engine on machine tool.

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For the characteristic of aerodynamics of boxes, below given data on

the speed of the air circulation and exhaust gases in the different cross sections of box for tests of TVD.

The entry of air in the suction part is produced at a rate of of 10-20 m/s. The average speed of air circulation through the silencer, during suction can be accepted as 20-30 m/s, also, of the leveling grid 15-20 m/s. In the plane, swept by screw/propellers (at output/yield from aerodynamic ring 4 in Fig. 106), the air speed is obtained from the calculation of screw/propeller. In the case when the efficiency of screw/propeller is equal to 0.55 (flight speed of V = 0), the speed is equal to 45 m/s.

In sound suppressors on exhaust, the speed is accepted order 30-40 m/s. The same approximately value has speed, also, at output/yield in the atmosphere. Due to air circulation, the pressure in the suction part of the box and engine cabin/compartment usually on 100-300 mm H_2O is lower than atmospheric, but before the exhaust silencer on 200-400 mm H_2O, it is higher. This fact must be considered during the stress analysis of box.

3. Compartments of control.

During engine, tests operating personnel is located in the cabin/compartment of control, arrange/located next to box. For providing the control capabilities with engine and the monitoring of its work, the cabin/compartment must:

1) to be sufficient for the arrangement/permutation in it of equipment, instruments and personnel;

2) to ensure the possibility of visual observation (through special windows) of the state of the tested in box engine;

3) to guarantee complete safety, that is located in cabin/compartment during personnel tests, to have good soundproofing and ventilation;

4) to be well illuminated (by day is desirable the natural illumination).

Depending on the number of serviced boxes of cabin/compartment, they can be individual (one-way or bilateral) and common/general/total. Common/general/total cabin/compartments they are called the cabin/compartments, which pperate more than two boxes. The best conditions for the service personnel can be created in individual cabin/compartment. More compact cheaper and more

convenient for technical direction of replacement (possibility of simultaneous observation of work of all crews, who operate units), is the general cabin/compartment of control.

A selection of one or the other type of cabin/compartments is determined by the planned program of the issue of engines, by their type and the power, accepted by the schematic of the arrangement/permutation of engine in box and by the construction of box.

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The sex/floor of the cabin/compartment of control is establish/installed in special columns and do not connect it with the walls of box, which substantially attenuate/weakens the vibrations, transferred from the tested engine.

In the cabin/compartments of experimental stations, they place the special equipment, basis of which is the control panel of engine, equipped with monitoring instruments.

Control panel is placed usually outside the plane of the rotation of the rotor of engine. On panel furnish: engine controls, its assemblies and the support systems: monitoring instruments; the

additional instruments, necessary for the measurement of the testers of values interesting; the signaling system. Above the panel is located observational window.

The basic requirement, presented to control panel, consists in the arrangement of instruments and controls making it possible with the greatest convenience to control/guide engine, to control instruments and to record/fix their readings.

Fig. 110, shows control panel. In the center section of the panel, are arrange/located the sectors of control, the pushbutton system of electric start and the instruments, which characterize the engine operation.

Nearer to center section are furnished the instruments whose readings must be record/written, are further - instruments chart recorders.

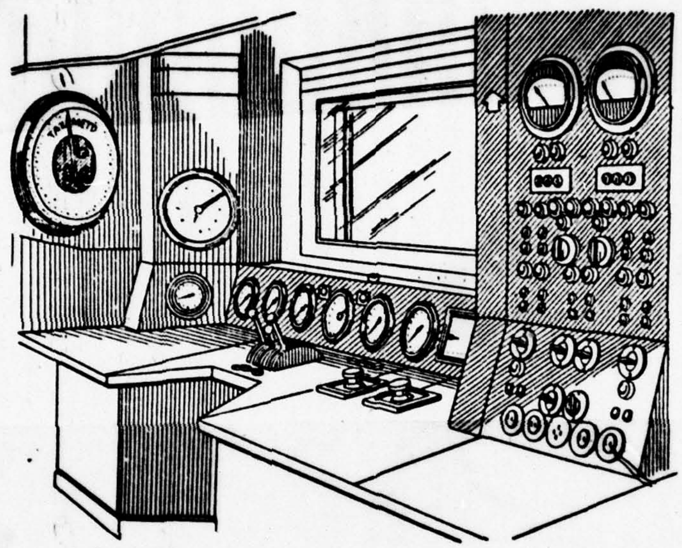

Fig. 110. Control panel.

Key: (1). Tachometer.

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One-type instruments or the instruments, intended for the measurement of the determined values, must be disposed of separate groups. Instruments with especially sensitive mechanisms one should

establish/install in the places, immune to to vibrations, in packing of sponge rubber.

On testing units the control panel is located on sufficiently large distance (4-6 m) from engine. Under these conditions the translation of motion from sectors on control panel to levers on the tested engine presents some difficulties.

The teletransmissions of control must provide:

1) the evenness of course and the absence of large friction;

2) tuning precision;

3) the constancy of the relative position of the lever of sector and adjustable lever;

4) insensitivity to vibrations and change in the ambient temperature;

5) rapid and light/lung connection to levers and disconnection from them.

As connection between sectors on panel and controls in engine

are applied thrust/rods with hinge joints, and also cable, electrical and hydraulic drives.

Operating experience showed that during careful control and with correct departure/care the drives of all indicated types work normally and provide reliable engine control. True, they all by no means to identical degree and in complete measure satisfy conditions placed above.

From listed drives considerable propagation received reliable and simple in control hydraulic drives. During the application/use of a cable transfer, meet the difficulties the elimination of the gaps, which mix the fine tuning of engine to the assigned mode/conditions. Electrical transferes limit the possibilities of tests, so they do not make it possible to produce the nonuniform displacement/movement of the sectors of control.

Fig. 111, shows the schematic diagram of hydraulic drive. Drive consists of transmitting and sensors, connected by tube. System fills with transformer oil or, with the wish to lower the viscosity of liquid, by the mixture of transformer oil with kerosene. Each of the cell/elements of drive is equipped by the piston, spring-loaded. In system is provided the identical displacement/movement of transmitting and sensors. Because of spring effect, the liquid always

is found.

The conduit/manifold between the transmitting (arrange/located on panel) and receiving (arrange/located on engine or machine tool) mechanisms can be laid in any place of box.

For convenience in the maintenance of unit during testing in the cabin/compartments of control, is used extensively light signaling (polychromatic incandescent bulbs, arrange/located on control panel).

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Thus, for instance, light signaling prevent/warns about the connection/inclusion of current at unit, about the beginning of training/preparation for starting/launching, about engine starting, about the presence of fuel feed for engine, etc.

The installation of the signaling systems (including of the system, which operates measurements) produce in dependence on the type of engine, of testing unit and the used with it arrangement systems of equipment.

In cabin/compartment it is desirable to ensure the complete exchange of air approximately during every 10-15 min. One should

entire fuel manifold consist into the special bellows, which has separate ventilation.

4. Testing units and their arrangement at station.

Are applied at present the testing units of two types (Fig. 112). A vital difference in them is in the arrangement of the tested engine in box relative to cabin/compartment and control panel. At the unit, given in Fig. 112a, the engine side-by-side to control panel, while at unit (Fig. 112b) - it is perpendicular.

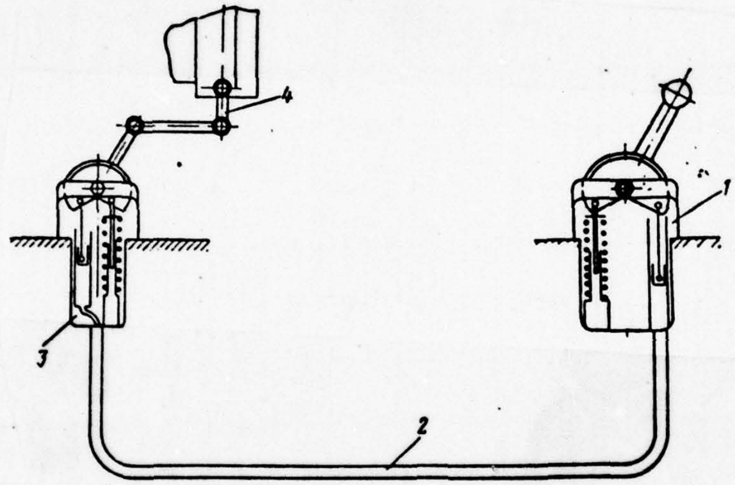

Fig. 111. Schematic diagram of hydraulic drive. 1 - the transmitting cell/element, 2 - conduit/manifold, 3 - sensor, 4 - lever on engine.

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In the first type of installations, the boxes are less complex by construction and by simpler resources satisfy aerodynamic

requirements. In second type, units is guaranteed the greater safety of the service personnel, since the rotation of compressor, turbine and propeller occurs in the plane, parallel to the cabin/compartment of control. Depending on the selected type of testing units, plan/glides their arrangement at station.

In Fig. 113 are shown four versions of the arrangement of installations. On diagrams Fig. 113a and b, are shown to station with the boxes in which the engines side-by-side to panels, while on remaining diagrams - station with the boxes in which the engines are arranged is perpendicular to panels. In some stations (Fig. 113a, b and d) are applied the units with the individual cabin/compartments of control (one-way - in Fig. 113a and bilateral - in Fig. 113b, d), while on others (Fig. 113c) - with the common/general/total cabin/compartment of control.

The boxes of all testing units must be imparted with exchange point/item 5, in which the engine is prepared for tests, and then they send into the shop of sorting/partition or to the storage of expedition.

On diagrams Fig. 113a, b, c shown single-row arrangement of testing units at station, while in the diagram Fig. 113d - two-row arrangement. The single-row arrangement of installations facilitates

the arrangement/permutation of station in the territory of plant, the centralized fuel supply, simplifies conditions of fire-fighting protection and the feed/supply of engines by pure air.

Besides locations indicated above basic, at station a considerable quantity of area is abstract/removed for auxiliary services. Area under auxiliary locations is selected and design on the basis of the corresponding norms.

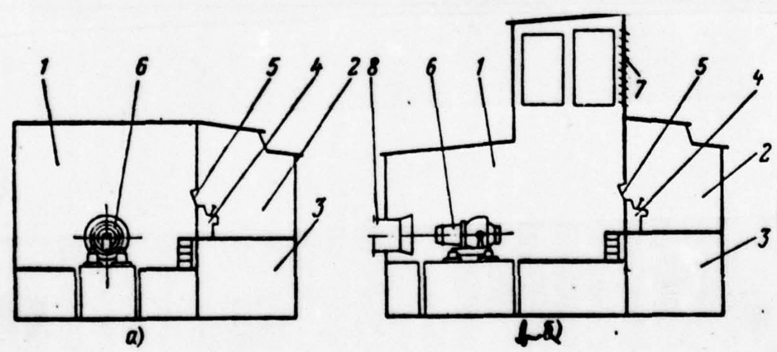

Fig. 112. Schematics of testing units. 1 - box, 2 - the cabin/compartment of control, 3 - technological location, 4 - control panel, 5 - inspection window, 6 - engine, 7 - the entry of air, 8 - ejection pipe.

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The part of the station where place auxiliary locations (storage, administrative-economic, public organizations and everyday), must be two-story. Area/site under station is abstract/removed usually of the boundary/interface of plant territory, next to assembly shop, in accordance with the ruling wind direction. Exhaust gases must not be taken away to the territory of plant. Near station must be the approach railway lines, which ensure the supply of fuel to fuel tank. Near from station must be furnished expedition, where they pass/return engines, successfully passed tests.

5. Test benches and the methods of determining the thrust/rod.

Thrust force must be determined with high degree of precision. During the measurement of thrust/rod, the permissible error must not exceed ±0.5o/o of the value of full thrust.

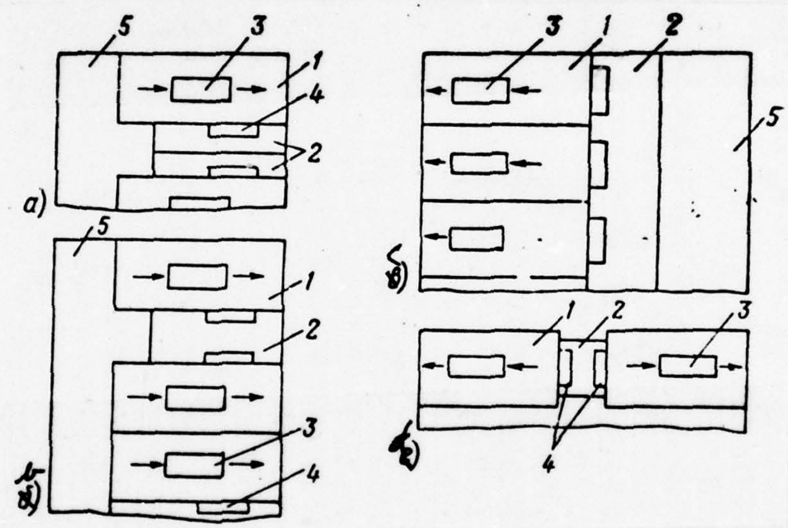

Fig. 113. Schematic of arrangement of testing units at station (by rifleman/pointers is shown direction of air circulation in box). 1 - box, 2 - the cabin/compartment of control, 3 - machine tool with engine, 4 - control panel, 5 - exchange point/item.

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All types of test benches must satisfy the following requirements:

1) to possess sufficient mechanical strength and rigidity with relatively small size/dimensions and weight;

2) not to create additional resistance on the approach of air to engine;

3) to provide the reliable fastening of engine and accessibility to it for the execution of the works, connected with its maintenance;

4) the construction of machine tools must allow/assume testing on them the different modifications of just one type engine;

5) guarantee sufficiently large service life.

All the applied machine tools can be broken into rigid and flexible. On rigid machine tools the frame with the fastened to it engine is fixed. Unlike them, the platform on flexible machine tools can be moved within the limits, limited by detents.

Determination of thrust/rod on rigid machine tools.

During testing on rigid machine tools the engine thrust determines by calculation on the basis of well-known formula (for the case - flight speed c = 0)

$$R=\frac{G_B+G_T}{g}c_5+F_5(p_5-p_0). \tag{118}$$

Formula (118) shows that for determining the value of thrust/rod it is necessary to know the area of jet nozzle F_5, and the expenditure/consumption of air G_B, the expenditure/consumption of fuel/propellant G_T, the outlet gas velocity from nozzle c_5, static pressure in nozzle edge p_5 and pressure in box p_0. This method is complex and bulky, furthermore, it is not possible with high degree of accuracy to measure the flow rate of air and the exhaust gas velocity. Therefore it is applied rarely.

If we into expression (118) substitute by the formulas, known from gas dynamics, value

$$G_B+G_T=G_r=$$

$$=F_5\sqrt{2g\frac{k}{k-1}\left[\left(\frac{p_5}{p_5^*}\right)^{\frac{2}{k}}-\left(\frac{p_5}{p_5^*}\right)^{\frac{k+1}{k}}\right]}\frac{p_5^*}{\sqrt{RT_5^*}} \tag{119}$$

and

$$c_5 = \sqrt{2g\frac{k}{k-1}RT_5^*\left[1-\left(\frac{p_5}{p_5^*}\right)^{\frac{k-1}{k}}\right]} \quad (120)$$

and to conduct uncomplicated conversions, then we will obtain expression for determining the thrust/rod in the following form:

$$R = 2\frac{k}{k-1}p_s\left[\left(\frac{p_5^*}{p_5}\right)^{\frac{k-1}{k}}-1\right]F_5 + F_s(p_5 - p_0). \quad (121)$$

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The value of adiabatic index k, entering the expressions (119) - (121), that depends on the composition of gases and temperature, with sufficiently high degree of accuracy it is possible to accept as constant.

During engine, tests is usually of interest the value of reactive thrust/rod, led to International standard atmosphere (international standard atmosph):

$$R_{np}=R\frac{1{,}033}{p_0}. \quad (122)$$

After substituting into expression (122) value of R from formula (121), we will obtain

$$R_{np}=1{,}033\,\frac{p_5}{p_0}F_5\left\{2\,\frac{k}{k-1}\left[\left(\frac{p_5^*}{p_5}\right)^{\frac{k-1}{k}}-1\right]+\left(1-\frac{p_0}{p_5}\right)\right\}. \quad (123)$$

Thus, for determining the led to International standard atmosph value of the jet/reactive thrust it is necessary to measure the medium complete and static pressures of gases at output/yield from jet nozzle and the pressure in box, and then to use formula (123).

The value of complete and static nozzle exit pressure can be determined with the aid of three combs, establish/installed at an angle of 120° to each other and united by common/general/total collector/receptacle for an averaging. For the case when pressure $p_5 = p_0$, formula (123) assumes the form

$$R_{\text{пр}}=2{,}066\frac{k}{k-1}F_{5}\left[\left(\frac{p_{5}^{*}}{p_{0}}\right)^{\frac{k-1}{k}}-1\right]. \qquad (124)$$

By gas-dynamic method on rigid machine tool thrust/rod is measured with accuracy less than with the aid of dynamometers on flexible machine tool, but completely satisfying the requirements for technical specifications with the delivery of series of TRD.

Determination of thrust/rod on flexible machine tools.

Wide acceptance obtained the method of the direct measurement of thrust force on flexible machine tools. In this case the engine is establish/installed in special platform or the frame which can be moved in direction of the developed with engine thrust. The displacement/movement of platform is determined by the device of force gauge and lie/rests within limits 0.2-3 mm. Usually platform has its detents, which limit its motion.

All flexible machine tools consist of transfer table (frame) and fixed mounting (basis).

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According to structural/design sign/criteria machine tools can be divided into three basic groups: machine tools with platform on rollers; machine tools with suspension platform and machine tools with the platform, strengthened to flexible rods.

By the first types of machine tools, which obtained propagation during testing of air-breathing engines, were machine tools with the platforms, establish/installed on rollers. They were characterized by low sensitivity and the poor stability of readings due to the high contact voltage/stresses in rollers and the rapid wearing capacity of their path/tracks. Therefore at present machine tools with platform in rollers are not applied.

Suspension platens can be suspend/hung to the ceiling of box or to the special buck stays, rigidly stationary. Considerably larger operational advantages possess machine tools with the platforms, suspend/hung to special buck stays. Depending on the kind of suspension the indicated category of machine tools can be broken in turn, into two forms: machine tools with the suspension of platform on connecting rods and machine tools with the suspension of platform

on elastic tapes.

Machine tool with the suspension of platform on connecting rods consists of four buck stays 1 (Fig. 114), rigidly attached on special foundation; transfer table 14, suspend/hung from four connecting rods 6; the mechanism of rodding to measuring device; two struts 10 and support 12 for fastening of engines in mobile platen.

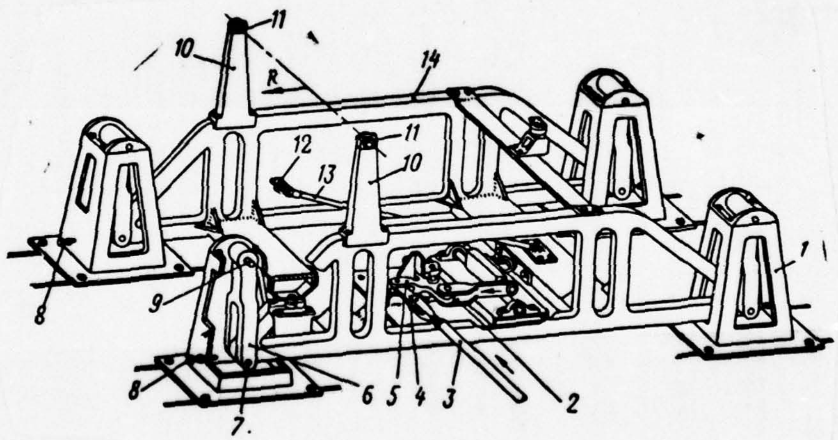

Fig. 114. Machine tool with suspension platform on connecting rods. 1 - the buck stays, 2 - branching/fork, 3 and 4 - thrust/rod, 5 -

g-shaped lever, 6 - connecting rods, 7 - lower finger/pins, 8 - the screw/propeller of detent, 9 - finger/pins, 10 - the strut of transfer table, 11 - tip bearing, 12 - the assembly of the third support, 13 - the thrust/rod of lower support, 14 - transfer table.

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The application/use of spherical (adjusting themselves) bearings in socket joints of suspensions makes it possible for platform easy to be moved under the action of effort/force. Small end of connecting rod is equipped by one bearing, and big end carried out in the form of branching/fork, has two bearings and is connected with the ear of platform 14 by finger/pins 7. The extent of movements lengthwise is limited to screw/propellers 8. Possible during operation of engine on machine tool the lateral displacement/movements of platform are limited to special detents. The permissible by limiters lateral displacement/movement of platform oscillates within limits 0.1-0.3 mm.

The displacement/movement of platen lengthwise, under the effect of the thrust force of the tested engine, composes a comparatively high value (2-3 mm); during such displacement/movements the hose of fuel system, connected to engine and which is located during testing under high pressure, introduces distortions into the accuracy of

measurement. It is not possible to decrease the displacement/movement of platform, since to it is impossible completely remove gaps in socket joints of machine tool.

The accuracy of the measurement of thrust/rod descends also due to lateral displacement/movements and the appearing in this case friction between guide bearing and the limiter.

Noninspection to the indicated shortcomings, machine tool sometimes it is applied in the practice of production type tests of VRD.

Fig. 115, shows the schematic of machine tool with the suspension of platform on elastic tapes. Platform 5 is connected with mounting by 2 four steel strips 3, fixed to the supports of platform and mountings power bolts. On strips there are special thickenings for the best fastening to supports.

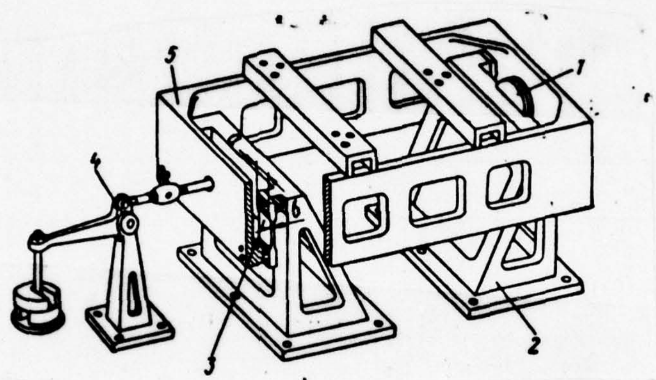

Fig. 115. Machine tool with suspension platform on elastic strips. 1 - dynamometer, 2 - mounting, 3 - elastic strip, 4 - device for calibration, 5 - platform.

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During the application/use of an elastic strip with ratio a/b on the order of 50, are absent the cross travels of machine tool, which raises the accuracy of the measurement of thrust/rod. Machine tool with tape/strip suspensions as compared with machine tool with

connecting rod suspensions is characterized by larger simplicity and reliability of supports (strips).

The displacement/movement of platen under the effect of the thrust force of the tested engine must be low (for the exception/elimination of the influence of the elasticity of strips) and at contemporary units does not exceed 0.5-1.5 mm.

Of some machine tools the platform is establish/installed in vertical flexible rods and limit its displacement/movement on 0.2-0.5 mm. Because of this low displacement/movement the accuracy/precision of the determination of thrust/rod is raised.

The indicated machine tools are very simple and it is expedient to apply them for the engines of low weight.

Of the schematics examined above of machine tools for determining thrust/rod the greatest propagation received the machine tools with the platforms, suspend/hung from elastic strips.

Calibration of machine tools.

For the purpose of obtaining the more precise readings of thrust/rod, one should on all types of machine tools create preliminary interference of transfer table. For this, it is expedient to provide lever/crank-tightening devices which simultaneously can be calibration instruments.

On platens, there are special attachments, employed for fastening of engine - the engine mounts. Of some types of machine tools, the engine mounts are absent, and engines are fastened to special assemblies directly on platform.

Points of attachment design so that not to limit the freedom of the motion of engine after starting/launching, because of the temperature expansions of some of its parts. Engine is fastened on machine tool at three points.

For the observance of the accuracy of the measurement of thrust/rod, all the connections with the power supply units and engine control make elastic. To achieve the absolute accuracy of the measurement of thrust/rod is impossible, due to the presence of forces of friction in the measuring system and influences of different compounds. In connection with this is necessary the calibration of machine tool together with the assigned to it measuring device.

The calibration of machine tool is produced with the assembled on it engine. Calibration is of two kinds: static with nonoperational engine and dynamic with worker. The dynamic calibration of machine tool is produced very rarely; therefore we will not it examine.

end section.

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For calibration are applied the special devices, temporarily establish/installed by row/series with machine tool, or lever/crank-tightening devices, entering the construction of some machine tools. With the aid of calibration instrument artificially is reproduced the load on machine tool, which corresponds in the direction to the engine thrust. Calibration instruments can be different in construction and in operating principle. Simplest and widely used in the practice of tests are lever/crank type calibration instruments.

Fig. 116 lever/crank type shown calibration device, two struts 7 which are fastened with bolts 8 to foundation along both sides of machine tool. The vertical position of struts regulates by detents 6 with the aid of trailer connection 5. In the upper part of the struts, are hinged attached L-shaped levers 11, connected with the aid of finger/pins 12 with trailers 16, which have trailer connection 15. To another end of the levers from rod 10, are suspend/hung cups 9 for the location of calibration loads. The second end of the thrust/rod through the branching/fork of 1 bracket 2 is connected

with struts 4 of transfer table of test bench. On lever 13, which is the continuation of lever 11, is attached counterweight 14.

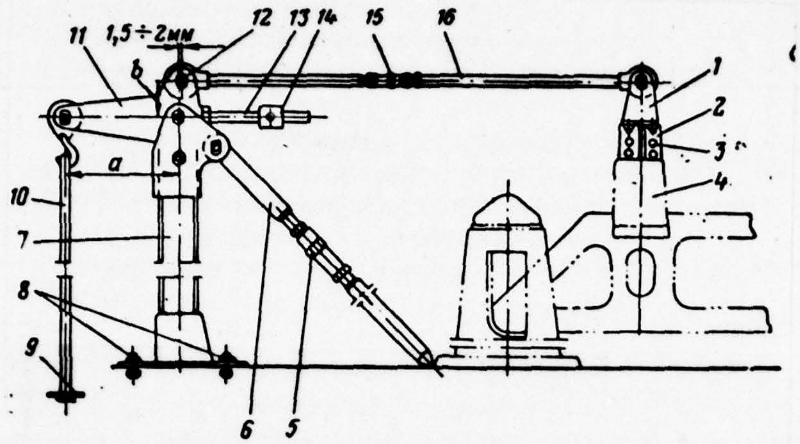

Fig. 116. Device for calibration of machine tools. 1 - branching/fork, 2 - bracket, 3 - the clamp bolts of bracket, 4 - the strut of mobile platen, 5 - trailer connection, 6 - detents, 7 - the strut of calibration device, 8 - the clamp bolts of struts, 9 - cargo cup, 10 - rod, 11 - L-shaped lever, 12 - finger/pin, 13 - lever, 14 - sliding weight of counterweight, 15 - trailer connection, 16 - thrust/rod.

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During the installation of calibration device the length of thrust/rod 16 with the aid of trailer connection is regulated so that the axle/axis of finger/pin 12, which connects thrust/rod with lever, would be misaligned to the side of engine to 1.5-2 mm relative to the

axle/axis of the finger/pin, connecting lever with the strut of device (length of thrust/rods in this case must be identical). Then are hung rods with load cups and to the rifleman/gunner of the measuring device of machine tool they establish/install in "0" by weight shifting 14 in levers 13.

For the calibration of the machine tool of cup 9, place the loads with a weighing of 10-25 kg and record/write readings of weighing device of the record sheet of calibration. Then consecutively increase load and record/write readings of draft gauge. Peak load must by 10-15o/o exceed the full thrust, developed with engine. In this case, it is necessary to consider the relationship/ratio of arms a and b of lever 11.

For testing of the sensitivity of machine tool to both cups, they add by equal portions the load, corresponding to weight 0.5o/o of measured or full thrust (that it depends on the effective technical specifications). If with the addition of this load are not changed readings of draft gauge, then it is necessary to unload calibration device and to test that are there no interferings in the component/links of machine tool, device or measuring device. The discovered defects must be removed, and the calibration of machine tool must be manufactured repeatedly.

After completion of the load of calibration device, they begin its unloading by the gradual taking of loads from cargo cups. In this case, also are record/written readings of measuring device on calibration accuracies on which they were record/fixed earlier than the reading with an increase in the load.

If in readings of draft gauge on the similar points, obtained with loading and unloading of calibration device, disagreement will exceed ±0.5o/o from full (or sometimes measured) thrust, then machine tool, calibration device and measuring device must be tested, but calibration must be repeated.

After the complete removal of load from calibration device, it is necessary to rock transfer table of machine tool and to give to it possibility to be balanced. In this case, the rifleman/gunner of the indicator of measuring device it must show the zero value of thrust/rod. At the termination of calibration, is constructed the calibration graph of machine tool according to the average data, obtained with load and unloading of calibration device.

The calibration of machine tool one should produce not thinner than one times in month, or before the prolonged and after endurance test of engine and after each sorting/partition of machine tool. In dependence on the device of machine tool, character of the conducted

tests and construction of calibration device the process of calibration can have its special feature/peculiarities, in connection with which the order of the calibration is indicated in the corresponding technical specifications and records.

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6. Test benches and the methods of determining the torsional moment.

By the basic parameter, which characterizes the effectiveness of turboprop engines, is the power, absorbed propellers. The direct measurement of power during test work is irrational. Usually effective power is determined by indirect method from the formula

$$N_e = \frac{M_{\text{кр}} n}{716{,}2}. \quad (125)$$

During the determination of the power of turboprop engines, it is necessary to focus special attention on methods and the accuracy/precision of the determination of the torsional moment. The permissible error according to the effective technical specifications must not exceed ± 0.5o/o of the maximum value of the measured torsional moment.

The methods of determining the torsional moment, used from experimental stations, are different. But in all cases the tested engine is installed on rigid (with fixed platform) or flexible bob machine tool (with the rocking platform).

Requirements for the indicated machine tools are identical to those given above requirements for machine tools for determining reactive thrust/rod.

Independent of the type of the machine tool on which is tested the turboprop engine, the necessary cell/element of testing unit is the brake, which absorbs the power of engine.

During testing of turboprop engines, find wide application air and hydraulic brake. As air brakes are applied propellers of engines. Air brakes are applied during engine testing both on rigid and on bob machine tools. Hydraulic brakes are applied only during engine testing on rigid machine tools.

Let us pass to the examination of the different methods of determining the torsional moment of turboprop engine.

Tests of turboprop engines on rigid machine tools with propellers and

hydraulic brakes.

Fig. 117, shows the machine tool, which is rigid open frame, attached on the foundation and carrying on themselves power frame 2 with engine mount 1. To the latter is fastened the engine whose power is absorbed by propeller. Machine tool is very simple by construction, it is convenient in operation, it is designed to engine testing of large power.

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Engine testing of smaller powers is possible during the uncomplicated conversion of machine tool - setting to the power ring of intermediate frame.

To apply air controllable-pitch propeller as a brake of this type of engine is possible, if the characteristic of the latter is entered into range OAVO (Fig. 118). Line OA corresponds to the maximum value of the blade angle Ψ_{max}, while line OV - the minimum value of the blade angle Ψ_{min}. Point A corresponds to the maximum torsional moment. Point V limits the maximum permissible from condition strengths of screw/propellers revolutions. Line AB characterizes power change with $M_{кр}$ = const.

The knowledge of dependence that which is absorbed by the screw/propeller of power on revolutions for different values ψ = const makes it possible in principle to determine the power of engine. But virtually method is applied rarely, since the characteristics of screw/propeller in work in box are not stable and cannot be obtained with the necessary degree of accuracy.

To determine torque on the shaft of the engine, tested on rigid machine tool with propellers as brakes, possible also at special torque meters (ГКМ) (see Chapter III).

Considerable propagation for absorption and measurement of power was received hydraulic brake. Fig. 119, shows the schematic of setting turboprop engine 3 on rigid machine tool 4 with hydraulic brake 1 as the absorber of power.

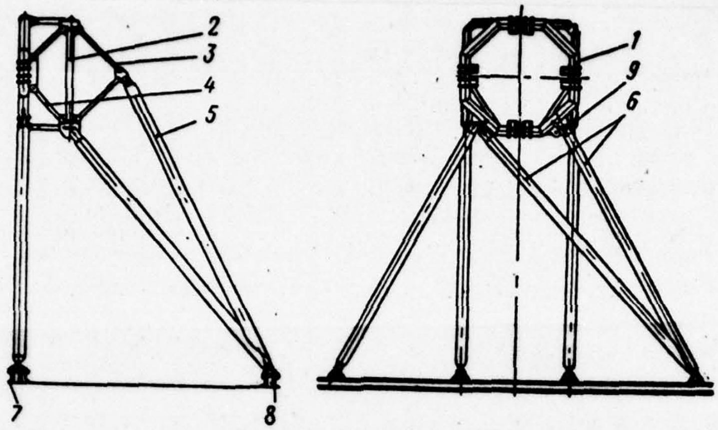

Fig. 117. Rigid machine tool for testing TVD with propeller. 1 - the engine mount, 2 - power frame, 3, 4 - braces, 5, 6 - strut, 7, 8 - data points, 9 - arms.

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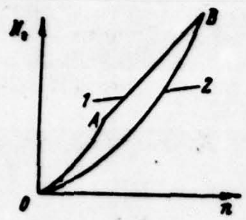
Machine tool is the rigid farm/truss, establish/installed on special foundation.

The operating principle of hydraulic brake is based on the use of resistance, which appears during the rotation of disks in liquid. The schematic diagram of hydraulic brake is shown in Fig. 120. To shaft 1, is mounted brake disc 2, which rotates in the housing of stator 5, which can be turned in bearings. Water along tube 3,

equipped with valve/gate 4, under constant pressure proceeds to the center of disk 2, whence under the action of centrifugal force it is reject/thrown to the periphery of disk. Discharge water is abstract/removed through tube 6. The thickness of the layer contained jacket water and, therefore, the power, absorbed by brake, regulate by rotary branch connections 8 with the aid of worm gear 7.

The hydraulic resistance, which effects on disk during its motion in a layer of water, creates braking moment. The latter is directed against the rotation of disk and balances the equal to it, but oppositely directed torsional moment, applied to the shaft of brake. Accomplished by engine work is converted into the heat, which heats water.



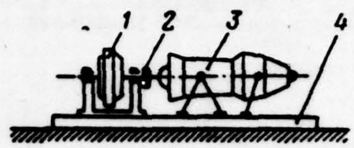


Fig. 118 Fig 119

Fig. 118. Characteristic of controllable-pitch propeller. 1 - with heavy screw/propeller, 2 - with the lightened screw/propeller.

Fig. 119. Schematic of setting of TVD on rigid machine tool with hydraulic brake as absorber of power of engine. 1 - brake, 2 - the coupling, 3 - engine, 4 - machine tool.

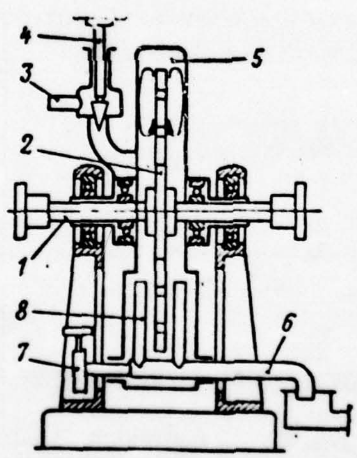


Fig. 120. Schematic diagram of hydraulic brake. 1 - shaft, 2 - brake disc, 3 - water supply, 4 - valve/gate, 5 - the housing of stator, 6 - drain, 7 - worm gear, 8 - rotary branch connections.

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To jacket it is transferred through water torque/moment, equal to braking moment, but oppositely directed. This torque/moment will turn jacket in the direction of rotation of rotor. The value of torque/moment is measured with the aid of dynamometers. So by hydraulic brake is measured the torsional moment.

Turboprop engines on hydraulic-brake stand can be experience/tested with reducer or without reducer. With reducer are carried out the tests of the subminiature motors, working in operation with one propeller.

To the hydraulic brakes, used during tests of TVD, are presented the following requirements:

1) reliable work in operation during is not less than 2000 hours;

2) an error in the measurement of the torsional moment must be not more than $\pm$0.5o/o maximum measured torque/moment;

3) the possibility of load change over wide limits with constant rpm;

4) simplicity in operation and ease of control.

With high rated speed of hydraulic brake for the tests of powerful TVD, they are obtained by sufficiently compact and light/lungs.

The requirements enumerated above satisfies Soviet hydraulic brake GT-Ye (Fig. 121). The hydraulic part of the housing consists of the chamber of filling A, of the chamber of braking B and of plenum chamber C. The chamber of filling is the cavity from which the water enters the chamber of braking; its designation/purpose - to align the pressure of liquid, which is very important from the viewpoint of the operational stability of brake. In the chamber of braking, mechanical energy is converted into thermal. The chamber of braking in circumference is closed by the ring of 10 average disks 9. Between the ring and body disks 7, are formed the slots for the yield of water from the chamber of braking into damping chamber. At stator on the surfaces, turned to the side of the disk of brake, have radial fin/edges for an increase in the drag coefficient of the chamber

walls of braking.

During operation in the chamber of braking, are store/accumulated the air and the water vapors, calling buffeting and the instability of work of hydraulic brake. For the elimination of this defect, the chamber of braking is prompted with the atmosphere. Water into brake enters through flexible hose from the chamber of the fixed level through controlled by electric motor valve 8. In other words, with the aid of valve is regulated value that which is absorbed by the brake of power.

On stator is establish/installed water pump 11, which feeds the ejector of hydraulic brake. Since pump 11 is given from the shaft of brake and is establish/installed on the housing of stator, the accuracy of the measurement of power it does not affect. Ejector provides the stable operation of hydraulic brake on all mode/conditions.

For the prevention of fouling, the temperature of the water, coming out from hydraulic brake, must not exceed 70-80°C.

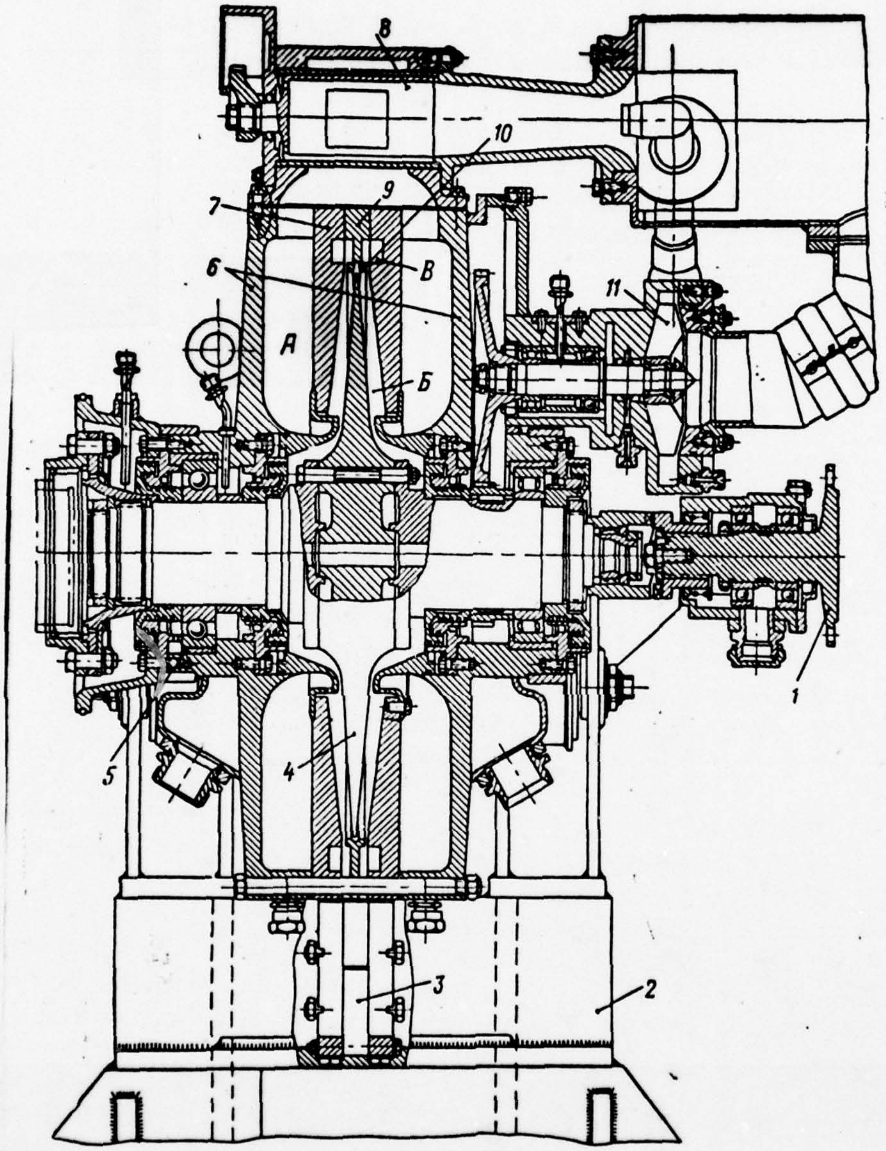

Fig. 121.

Fig. 121. Hydraulic brake GT-Ye. 1 - Acceleration clutch, 2 - support, 3 - drainage nozzle, 4 - disk, 5 - bearings, 6 - bearing flanges, 7 - body disks, 8 - valve, 9 - average disk, 10 - damping ring, 11 - water pump. A) the chamber of filling, B) the chamber of braking, C) plenum chamber.

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The accuracy of measurement of the torsional moment depends on the value of bearing friction and the rigidity of the conduit/manifolds, which supply water. The lesser the rotation of stator, the higher the accuracy of measurement. Conduit/manifolds (hoses) must be soft.

The torsional moment, which effects on stator, is transferred to measuring device. To the housing of hydraulic brake, they fasten on lever (Fig. 122). The lever of calibration 5 serves for the perception of effort/forces from the weight of the loads, placed on calibration instrument 4. Working lever 2 transfers the effort/forces, which appear from reacticnary torque, to dynamometer 1.

The size/dimensions of the disk of hydraulic brake are selected

on the basis of calculation. Examining the friction from two sides infinitesimal circular cell/element of the disk of brake against water and after integrating differential equation, we will obtain formula for determining the friction horsepower of the disk

$$N_{\text{д}}=\frac{\varphi n^3(r_{\text{н}}^5-r_{\text{в}}^5)}{C}, \tag{126}$$

where φ is the coefficient, which characterizes the frictions of disks in liquid to magnitude of losses;

$r_{\text{н}}$ and $r_{\text{в}}$ - outside and inside radii of the disk of brake in m;

n - the number of revolutions of the rotor of brake per second;

C-constant number.

The calculation of hydraulic brake GT-Ye was produced by the semiempirical formula

$$N_{\text{д}}=C_{\text{д}}\left(\frac{2a}{1+a}\right)^{1,8}\left(\frac{\nu}{2}\right)^{0,2}\frac{\pi\rho\omega^{2,8}(r_{\text{н}}^{4,8}-r_{\text{в}}^{4,8})}{1380}, \tag{127}$$

where $C_{\text{д}}$ is the constant coefficient, characterizing the resistance of disk (for a brake GT-Ye $C_{\text{д}}$ = 0.209);

a - the constant coefficient, characterizing the effect of the

fin/edges of the walls of body disks on the amount of the absorbable power (for a hydraulic brake GT-Ye it is accepted $\alpha = 5$);

μ - the angular velocity of disk in 1/s;

ν - the kinematic viscosity coefficient of the working liquid in m^2/s;

ρ is density of working fluid in kg s^2/m^4.

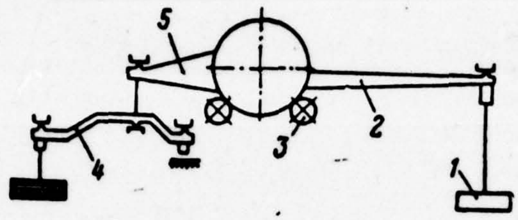

Fig. 122. Schematic of calibration instrument and measurements of torsional moment. 1 - dynamometer, 2 - working lever, 3 - rollers, 4 - calibration instrument, 5 - the lever of calibration.

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Values ν and ρ are determined according to mean temperature of water at entrance and exit of brake, usually t_{cp} = 40-45°C. Using formula (127), it is possible to construct the characteristic of hydraulic brake with its complete filling, i.e., the dependence of maximum power on number of revolutions.

According to the calculated power determine the consumption of the water through the hydraulic brake:

$$Q=\frac{632\cdot N_{\text{A}}}{\Delta t}, \qquad (128)$$

where Δt - the temperature differential of water at entrance and exit of brake, usually Δt = 35-45°C.

From Q is designed the cross section of conduit/manifolds on the entry into hydraulic brake. The velocity of water in conduit/manifold is recommended to accept within limits 2-3 m/s. Value Q is utilized also for the calculation of the flow areas of throttle/choke, water pump of ejector and drainage nozzles. Maximum pressure in kg/m², developed in the chamber of braking, they calculate according to the expression

$$p_{max}=\frac{\rho}{2}(r_{н}^{2}-r_{в}^{2})\left(\frac{\omega}{1+a}\right)^{2}. \qquad (129)$$

On the developed pressure can be found the effort/force, which is necessary to the chamber wall of braking.

Fig. 123, depicts the characteristic of hydraulic brake. If the characteristic of the tested engine is entered into the area, limited by lines OABCDO, which means, that this brake can absorb its power and measure torque. The initial section of characteristic OA corresponds to work of brake with maximum filling with water and is curved, close to cubic parabola.

In point A, the torque/moment reaches maximum value. A further increase in the number of revolutions of brake is admissible during a decrease in the thickness of the layer of water in brake so that on section AB the torsional moment it would remain constant and equal to maximum value.

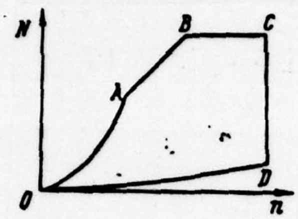

Fig. 123. Characteristic of hydraulic brake.

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In point B, the power, absorbed by brake, reaches maximum value. Its further increase is led at the beginning of boiling the water, which fills brake. At point C, is reached the maximum angular velocity of the rotor of brake.

Line OD of characteristic shows the minimum power, absorbed by brake without water because of bearing friction of rotor and friction of disk against air.

The calibration of hydraulic brake with torque meter is realize/accomplished with the aid of the calibration instrument, which consists of levers, thrust/rods and loads; the schematic of device is given in Fig. 122. The method of the calibration of

hydraulic brake is similar to the method of the calibration of machine tool for the measurement of thrust/rod. Requirements for the accuracy/precision of the calibration of hydraulic brake the same as during the measurement of reactive thrust/rod.

The calibration of hydraulic brake is carried out in the periods, stipulated under technical specifications for testing of this engine, and after all sorting/partitions or the preventive inspections.

A shortcoming in hydraulic brakes during testing of high-powereds engine with coaxial propellers, is the need for taking reducer, as a result of which the power of engine is determined without taking into account of losses in this assembly.

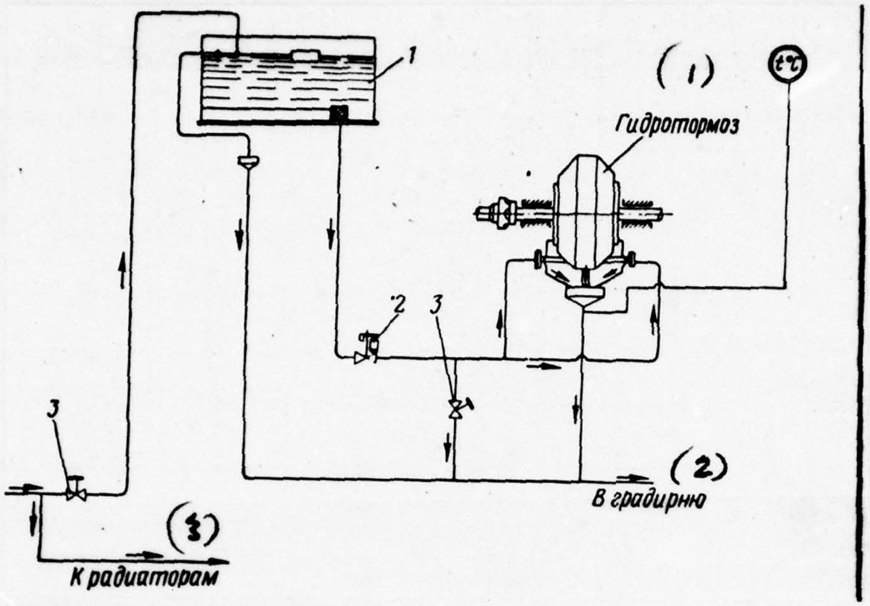

Fig. 124. Hydraulic system of setting. 1 - the tank of fixed level, 2 - bolt with electric drive, 3 - valve/gates.

Key: (1). Hydraulic brake. (2). In calibrator. (3). To radiators.

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The application/use of a hydraulic brake as absorber of the power of the tested engine is added to all systems of testing unit one additional - the water system, schematic diagram of which is shown in Fig. 124. Water from water pipe enters the tank of fixed level 1, whence through the filter and controlled bolt 2 - into

brake. Discharge water, and also surplus water from tank 1 heads for the saltpan where it is cooled, after which returns to the tank of fixed level. System not complex, but during testing of high-powereds engine must possess large throughput capacity.

During engine testing with air or hydraulic brake sometimes as starter is applied bob electric motor (Fig. 125). Bob electric motor allows simultaneously with the acceleration of the started an engine to determine the value that which is absorbed by it power at starting/launching. The torque/moment, applied to the stator of electric motor, is measured just as of hydraulic brake, with the aid of levers and measuring device. After having emerged of engine to working revolutions, bob electric motor is disconnected.

Fig. 126, shows rigid machine tool for testing TVD with propellers as brakes and bob electric motor 6, which performs the role of starter. On figure is visible dynamometer 9, employed for determining value that which is absorbed by the engine of power into the torque/moment of starting/launching and the calibration instrument of 7 bob electric motor.

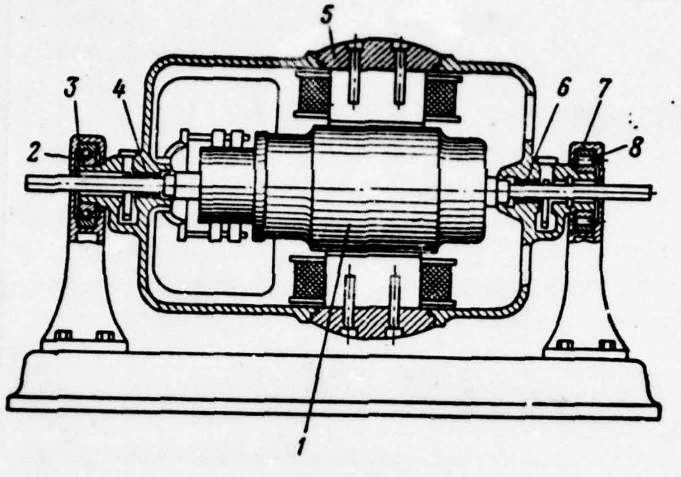

Fig. 125. Bob electric motor. 1 - anchor, 2, 8 - the bearings of stator, 3, 7 - strut, 4, 6 - spin bearings, 5 - stator.

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Engine tests on bob machine tools.

The power of turboprop engine can be determined on bob machine tool. The brakes, which absorb the power of engine, serves propeller.

Fig. 127, shows the schematic diagram of bob machine tool. Machine tool consists of fixed mounting 3 and rocking around

axle/axis O of frame 4. Tested engine 7 is establish/installed in frame. In the engine operation screw/propeller 8, being rotated counterclockwise, is created on the axis of fluctuation of frame reactionary torque in the direction of arrow/pointer. Reactionary torque, equal in magnitude to shaft torque of screw/propeller 8, turns to certain angle frame and lever 5, which moves thrust/rod 2, connected with torque meter. The calibration of machine tool with the aid of device 1 is carried out analogously with the calibration of machine tools for the measurement of thrust/rod.

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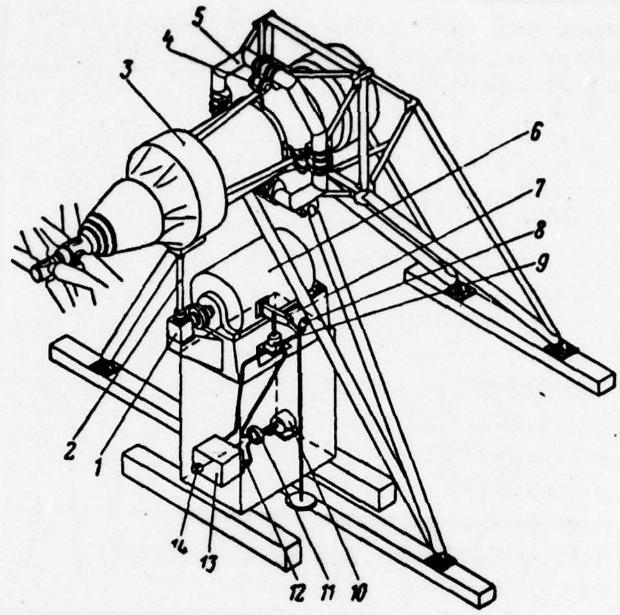

Fig. 126. Rigid machine tool for testing TVD. 1 - reducer, 2 - coupling shaft, 3 - engine, 4 - damper, 5 - machine tool, 6 - bob electric motor, 7 - device for the calibration of bob electric motor, 8 - manometer, 9 - dynamometer, 10 - electric motor, 11 - pump, 12 - filter, 13 - fuel tank, 14 - electric heater.

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Necessary requirement for bob machine tools - the arrangement/permutation of the center of gravity of the rocking

system below center of fluctuation. The axle/axis of engine usually coincides with the axle/axis of the rocking system or arrange/located somewhat above.

To the accuracy of measurement of the torsional moment $M_{кр}$ has effect the torsion propellers of the flow, which flows around engine. The twisted air jet decreases the real torsional moment to 2-3o/o.

It is known that the axial yield of gases from turbine is observed only in the engine operation on design conditions. The analysis of experimental material shows that the torsion of the coming out from turbine gas jet can introduce the error, which reaches to 10o/o of the measured value $M_{кр}$.

For the purpose of the elimination of the effect of the blowout of engine those who were twisted with propellers with flow one should engine cover during tests by the quick-detachable cowling, made from sheet steel and fixed to fixed mounting, or to place between it and with propeller diffusor grid.

For the elimination of effect on the measurement $M_{кр}$ of the torsion of gas flow behind turbine one should establish/install in output/yield from the jet nozzle of engine attached in cradle diffusor grid.

When conducting of the indicated measures, it is possible to measure the torsional moment of TVD with the error, which does not exceed ± 2o/o.

As can be seen from that which was presented, the accuracy of measurement of the torsional moment during engine testing on bob machine tools does not correspond to the requirements for technical specifications.

the greatest accuracy of measurement of the torsional moment provide hydraulic brakes. Promising is engine testing on rigid stands with air brakes and PCM for determining value $M_{\text{кр}}$.

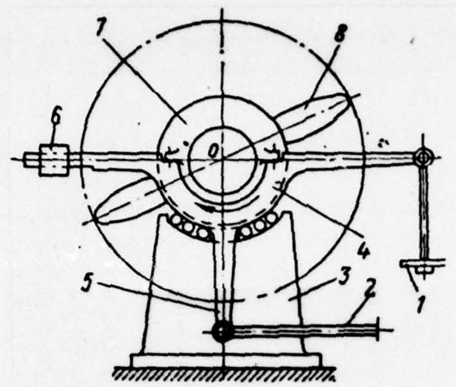

Fig. 127. Schematic diagram of bob machine tool. 1 - calibration instrument, 2 - rodding, 3 - fixed mounting, 4 - frame, 5 - lever, 6 - regulating load, 7 - engine, 8 - propeller.

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7. Machine tools for the measurement of equivalent horsepower TVD.

Efficiency of TVD is estimated at the equivalent horsepower, which is the sum of effective shaft horsepower and the power, created by reactive thrust/rod. Under conditions of bench tests of engine this power can be determined by the expression

$$N_{э}=N_{e}+0{,}91\,R_{c}, \quad (130)$$

where 0.91 is a conversion factor of the thrust/rod of power;

N_e - the effective power:

R_c - a jet/reactive thrust/rod of nozzle.

Thus, for determining $N_э$ necessary to produce simultaneously it died the torsional moment $M_{кр}$ and the jet/reactive thrust/rod of nozzle R_c.

Stand for determining equivalent horsepower consists of the cell/elements, which make it possible to produce the simultaneous separate measurement of the torsional moment and thrust/rod.

Equivalent horsepower can be defined during the engine installation both on rigid and on flexible machine tools. In this case, reactive thrust/rod on rigid machine tool it is expedient to determine by gas-dynamic method, but the torsional moment - one of the methods examined above.

Limited application for determining the equivalent horsepower

find the machine tools in which in transfer table are installed an engine and the hydraulic brake, which absorbs its power. The schematic of this machine tool is represented in Fig. 128. To mounting 5 from tapes 4, is suspend/hung platform 3. On platform is establish/installed engine 2 whose power is absorbed by hydraulic brake 1. The thrust/rod, created by the coming out from jet nozzle gas flow, is measured by dynamometer 6. The indicated method provides the high degree of accuracy of the definition both the thrust/rod of jet nozzle and the torsional moment of engine. The setting in question is bulky, complex and not always rational.

The calibration of dynamometers for the measurement of thrust/rod and torsional moment on the examined machine tools is produced separately, but with the established/installed engine, equipped according to technology.

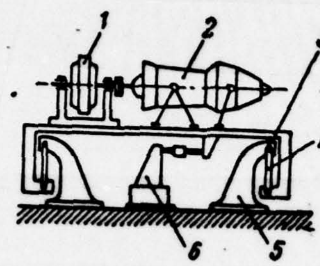

Fig. 128. Machine tool for determining equivalent horsepower. 1 - hydraulic brake, 2 - engine, 3 - transfer table, 4 - elastic tapes, 5 - mounting, 6 - dynamometer.

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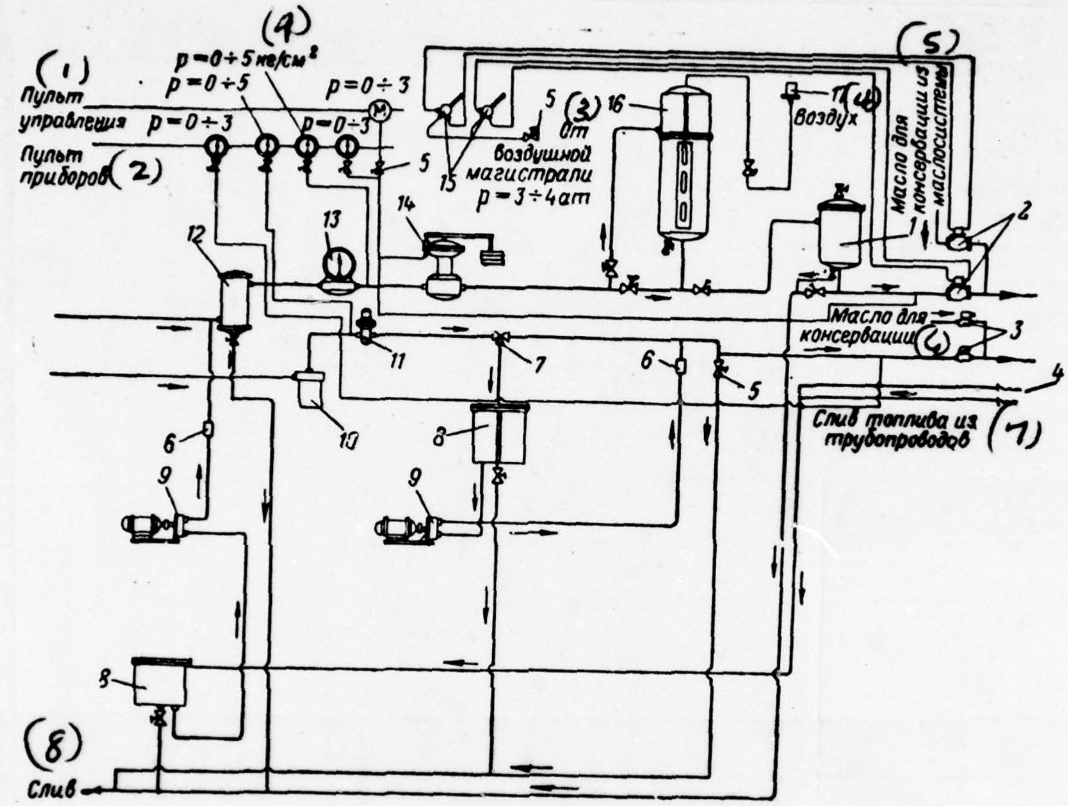

Fig. 129. Diagram of fuel system of experimental station. 1 - filter, 2, 3 - air operated valves, 4 - flexible hoses, 5 - valve/gates, 6 - check valve, 7 - three-way cock, 8 - measuring tank, 9 - pumping unit, 10 - the filter of purification/cleaning priming fuel, 11, 14 - automatic pressure regulator, 12 - the coarse filter of fuel/propellant, 13 - the counter of the fuel consumption, 15 - the tap/crane of the compressed air, 16 - fuel meter, 17 - fire safety device/fuse.

Key: (1). Bullets of control. (2). Panel for instruments. (3). From air line. (4). Air. (5). Oil for storage from lubrication system. (6). Oil for conservation. (7). Pouring fuel/propellant from pipes. (8). Drain. (9). kg/cm^2. (10) at.

end section.

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8. Systems of testing unit.

For providing the possibility of the test work of engines and taking the stipulated under technical specifications characteristics, the testing units equip with fuel and oil systems, the systems of load, starting/launching, etc. Let us examine some of the indicated systems.

Fuel system.

The fuel system of installations on testing VRD must ensure:

1) the uninterrupted feed/supply of engine by the necessary quantity of fuel/propellant in all range of the modes of its operation;

2) the possibility of the rapid measurement of the fuel consumptions in all engine power ratings with the error, which does not exceed ±0.5o/o;

3) careful air-department/separation and the filtration of the supplied to engine fuel/propellant;

4) supply to engine sometimes of two different types of fuel/propellant (starting/launching and basic);

5) convenience by operation and airtightness.

Fuel/propellant is fed to the engine through the service tank, arrange/located at testing unit, or it is direct from fuel reservoir. Contemporary VRD expend/consume considerable quantities of fuel/propellant. Therefore almost everywhere in experimental stations is applied the system of direct fuel feed to engine from central fuel reservoir. Fuel/propellant is fed along tubes with the cross section, sufficient for continuous feed/supply of several engines on, and the pressure of fuel/propellant in system is supported equal to 1-1.5 atm(gage).

The schematic diagram of the fuel system of unit with direct supply is given on Fig. 129. Main fuel from central fuel reservoir is fed to the coarse filter of fuel/propellant 12. Then through the total counter of the consumption of fuel/propellant 13 for automatic controller of pressure 14, which supports the necessary pressure in grid/network. From regulator the fuel/propellant heads for the engine through flow meter 16 of the volumetric or weight type. Through filter 1 and air operated valve 2, fuel/propellant enters engine. Air operated valve is intended for the cutoff of fuel/propellant in the case of the origination of fire hazard. Between flow meter 16 and filter 1, it is expedient to place the rotameter, which makes it possible to continuously check rate of discharge and to follow the stability of engine power ratings.

Priming fuel heads toward the engine through filter 10, the automatic pressure regulator 11 and fire magnet cranes of remote control 3.

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For the measurement of the consumption of priming fuel, serves measuring tank 8. In fuel system must be the drain line, through which surplus fuel/propellant enters conversely in fuel reservoir.

The taken centralized supply of installations with fuel/propellant provides uninterrupted feed/supply of engines and fire safety. Fuel reservoir usually consists of the service tanks, the pumping plant, which feeds fuel/propellant to units, and the drainage station, which pumps over fuel/propellant from the railroad tank cars in the capacity of fuel reservoir. To units the fuel/propellant is fed on three main lines: on two - main fuel (different types) and on one - starting/launching. In each main line there is a separate pump, which creates the necessary overpressure. Pressure constancy in system is supported by the reduction valves, which pass the excesses of fuel/propellant back into cisterns.

Fig. 130, gives the exemplary/approximate schematic of the arrangement of cisterns and equipment of central fuel reservoir with pump feed of fuel/propellant to units.

The fuel/propellant, which enters the engine, passes careful purification/cleaning. Usually in fuel system is provided for the setting of two filters: rough cleaning and fine purification. The filters, connected in system, must have the low coefficients of hydraulic resistance and retard the particles with a size/dimension of more than 5 μ.

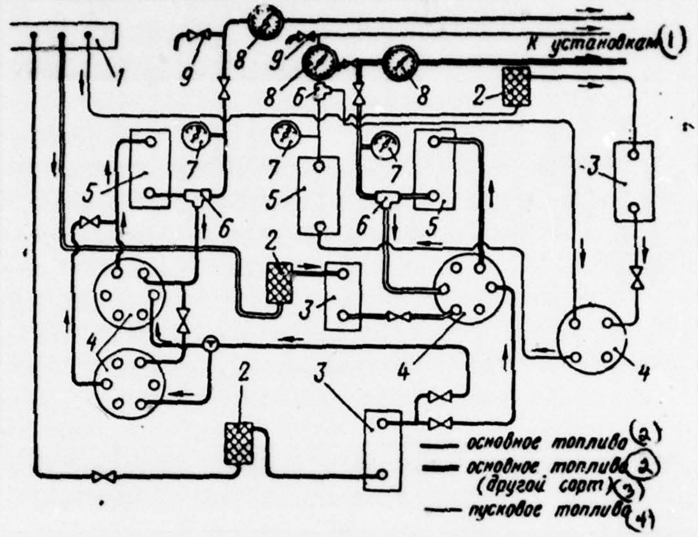

Fig. 130. Schematic of central fuel reservoir. 1 - drainage point/item, 2 - filters, 3 - transfer pumps, 4 - capacitance/capacity, 5 - the forcing pumps, 6 - reduction valves, 7 - manometers, 8 - flow meters, 9 - tap/cranes.

Key: (1). To units. (2). main fuel. (3). (another type). (4). priming fuel.

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As material for a filter, are applied silk (kapron) fabric or the special rubberized paper. Construction of one of the filters is

shown to Fig. 131.

The selection of the area of filter surface area depends in essence on rate of discharge of fuel/propellant, permissible resistance of filter and on the predicted frequency of sorting/partition.

Tap/cranes systematically are checked against airtightness under pressure, large of worker.

The cross section of main-line fuel pipe is selected so that the speed of the motion of fuel/propellant would be 1-2 m/s. For decrease in the possible losses of pressure, the bending radii usually are made more than three diameters of conduit/manifold.

All the compounds of main line must be easily open-door and rapid replacement. In order to eliminate the effect of fuel pipes on the measurement of thrust/rod or torsional moment of engine (during engine testing on the flexible machine tools), the fuel main directly of test bench they connect up engine with the aid of flexible hose.

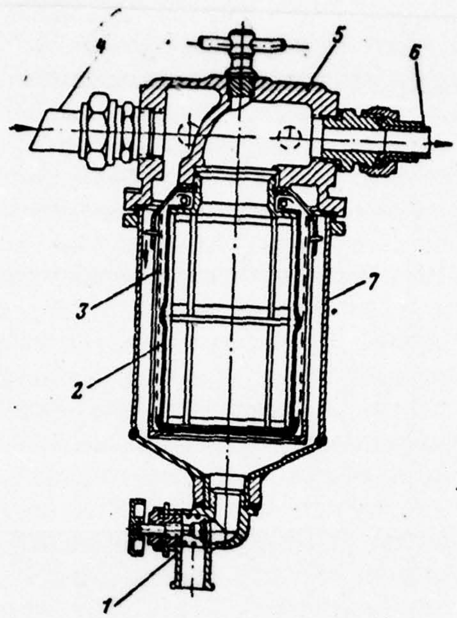

Fig. 131. Fuel filter. 1 - the drain cock, 2 - silk, 3 - the framework/body of the filtering cell/element, 4 - the branch of fuel input, 5 - upper lid, 6 - the branch of the branch/removal of fuel/propellant, 7 - housing.

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Fuel system is checked against airtightness under pressure, large of service pressure it is not less than two times and not thinner than one times in month.

Oil system.

Contemporary turbojet engines have the not dependent from aircraft (autonomous) oil system whose loose parts (capacitance/capacity, radiators, etc.) are structurally carried out in concert with engine. Therefore for production type tests of engine, the system of external oil circulation at unit is not necessary. Usually at stands of TRD, equip only oil system, intended for the conservation of engine.

For cooling of the rubbing parts of reducer of TVD, is required the considerably larger circulation of oil, than in TRD and therefore at stands of TVD is necessary the external oil system, which satisfies following requirements.

1) system must ensure supply into the engine of the necessary quantity of oil, and also conducting of the measurements of circulation and consumption of oil;

2) oil, coming out from engine, must be cooled, and inlet temperature into engine - be supported within certain limits;

3) oil, coming out from engine, must be filtered;

4) before engine starting under conditions of the low temperatures of surrounding air must be provided the possibility of the preheating of oil.

Fig. 132, gives the schematic diagram of the oil system of stand of TVD. Oil from special location is fed to tank 4, establish/installed on weighing device 5, through the indicators of the duct of oil 7. Location for oil tanks usually is designed for supply to the testing units of two types of oils and procedure from these installations of waste oil. Tank 4 is equipped with electric heater. From tank oil through the filter is fed to engine. On output/yield from engine, oil passes filter 10 (from brass grid) and heads back for the tank through total flow meter 2, which makes it possible to determine the circulation of oil. In system there is water-oil of radiator 1, with the aid of which it is possible to determine heat emission into oil.

Two in parallel connected filters at output/yield from engine they allow, without stopping tests, to disconnect one of them and to conduct inspection. Pumping unit 3 makes it possible to warm

thoroughly oil in an entire system. For this, the system must be preliminarily rung with the aid of tap/cranes 12.

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During engine, testing are distinguished the consumption and the circulation of oil. By consumption is understood a quantity of oil, spent by engine per hour of work. The circulation of oil he is called a quantity of oil, pumped through through the engine in a minute.

Consumption is determined by a change of weight or volume of oil in the tank of unit for the determined time interval. With the measurement of consumption volumetrically it is necessary to maintain the identical temperature of oil in the beginning and end of the measurement.

The measurement of circulation is produced during minute at steady temperature of oil. A quantity of pumped oil is determined from the formula

$$G_{м}=V_{м}\gamma_{м}=V_{м}[\gamma_{м\,20^{\circ}C}-0{,}007(t_{м.вых}-20)], \qquad (131)$$

where $V_{м}$ is a volume of pumped oil;

$\gamma_{м\,20^{\circ}}$ s - the specific gravity/weight of oil at 20°C;

$t_{м.вых}$—the temperature of oil at output/yield from article.

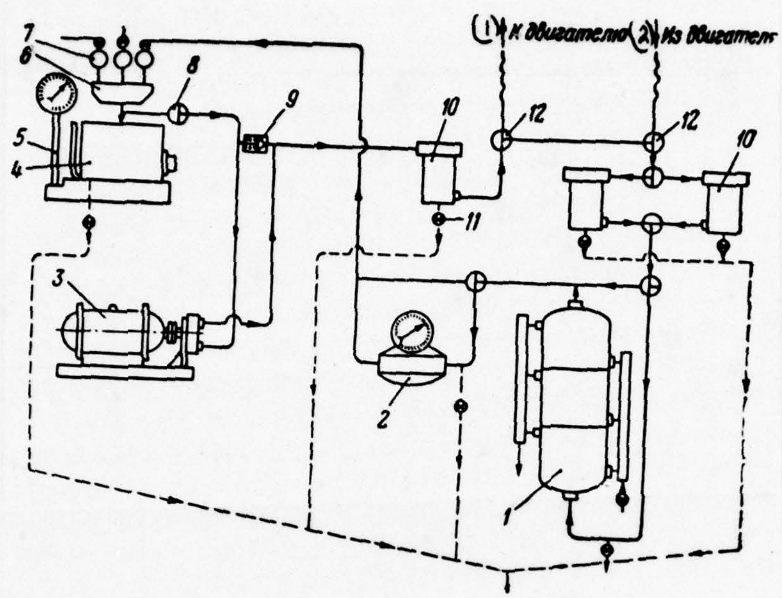

Fig. 132. Schematic diagram of oil system. Conditional designations: - oil feed, - oil drain, - flexible hose. 1 - water-oil radiator, 2 - total flow meter, 3 - pumping unit, 4 - weight oil tank, 5 - weights, 6 - drip pan, 7 - the indicator of the duct of oil, 8, 12 - three-way cock, 9 - reverse valve, 10 - filter, 11 - tap/crane.

Key: (1). To engine. (2). From to engine.

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In the value of circulation, it is possible to find heat emission in oil from the expression:

$$Q_м = c_м (t_{м.вых} - t_{м.вх}) G_м. \quad (132)$$

where $t_{м.вх}$ is temperature of oil at entry; $c_м$ - the heat capacity of oil.

$$c_м = 0{,}43 + 0{,}011 \left(\frac{t_{м.вых} + t_{м.вх}}{2} - 15 \right). \qquad (133)$$

The used in oil system radiators are tubular type common water-oil radiators. Oil occur/flow/lasts within the washed by water of tubes or, on the contrary, between tubes, along which flows the water. Oil pressure in radiator must be somewhat higher than the pressure of water.

The diameters of the conduit/manifolds of oil system one should select from the condition so that the speed of oil circulation would not exceed 1 m/s.

All engines, passed monitoring tests, subject to internal and external conservation. Internal conservation engine passes at station, external - during expedition. Internal conservation consists of two stages. After completion of monitoring test before the engine shutdown into its fuel system instead of the fuel/propellant, feed oil (see Fig. 130). The conservation of the remaining assemblies of engine is carried out on special trucks in exchange hall, where engine heads after tests.

9. Calculation of a required quantity of machine tools.

The number of machine tools n at station can be determined by the formula

$$n = \frac{\sum T}{\Phi}, \tag{134}$$

where $\sum T$ is a total gas labor consumption of tests in machine-hours;

Φ - the real fund of the operating time of one machine tool in hours.

The total gas labor consumption of tests depends on the program of the issue of engines N, of a quantity of hours of tests and time, necessary for the auxiliary activities when engine is located on machine tool. This time during any tests is composed of following elements: the time of installation on machine tcol and its equipment, warming up and the breakings in of engine, testing and timing of engine, of visual inspection, routine maintenance work (for engines which are found on prolonged or special tests) and of taking engine from machine tool.

Let us designate the total time of the determination of engine on machine tool during installation works and the tests: delivery - A, control - B, special - C, prolonged - D and repeated - E. Values A, B, C, D, and E are determined by test program. A quantity of engines, which pass special tests, is taken as equal to K_1 = to 0.025 N. A quantity of engines, which pass endurance test K_2, is determined by technical specifications for tests. upon consideration of the value of the load of machine tool during endurance tests, it is necessary to add 20o/o to routine maintenance work. A quantity of engines, which pass repeated tests, is taken as equal to K_3 = 0.1 to N. The time of repeated testing is taken equal to the time of delivery and control, i.e., E = A + B. Consequently, total annual labor consumption in hours can be determined by the formula

$$\sum T = [1,1(A+B)+0,025C+1,2K_2D]\,N. \qquad (135)$$

The real fund of the operating time of one machine tool per annum is less than calendar (being product number of workdays in year by the possible diurnal load of machine tool) due to time losses for repair of equipment, preventive maintenance and idle time:

$$\Phi = k\Phi_{\text{кал}}, \qquad (136)$$

where k - the coefficient, depending on the degree of the complexity of machine tool, the characteristics of engine and degree of the deterioration of equipment. Usually are accepted k = 0.85-0.95.

In the year of 359 workdays, if we consider that the station

works 24-hour with the extent of replacement 6 hours, then $\Phi_{\text{кал}}$ = of 359 workdays x 4 shifts x 6 hours = 8616 hours. In final form the formula for determining the number of machine tools can be represented in the form

$$n = \frac{N[1,1(A+B)+0,025C+1,2K_2D]}{k\Phi_{\text{кал}}}. \qquad (137)$$

If n is obtained by fraction, it is necessary to round off it to a whole to the side increase. For producing necessary reserve of the power of station, one should equip station with the number of machine tools n' = n + 1.

10. Methods of noise abatement at experimental stations.

At experimental stations appears the noise during suction, and especially during the outflow of gas behind jet nozzle. During testing TVD, additional noise is created by propellers.

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It is necessary to keep in mind that exhaust noise of jet engines is high-frequency, i.e., especially harmful for health. The questions of noise abatement at units with jet engines are important not only for the service station personnel and the collective of

plant, but also for the population, which lives in area of the latter.

Fig. 133 are represented these, characterizing change noise intensities at a distance 9 m around the engines of different types, approximately equal thrust indices. An increase in the distance to 90 m decreases noise intensity approximately by 20 dB.

Decibel is a unit of ncise intensity. A quantity decibel is determined by the expression

$$L=10\lg\frac{I}{I_0}\ \partial б, \quad (138)$$

where I is the force of the volume of source; I_0 - the force of volume on threshold of audibility, is equal to 10^{-9} erg/cm²s = 10^{-16} Joules/cm²s.

In order to present physically the value of the noise of jet engines and to clarify the value of the prcblem in question, we will use, by Fig. 134, which shows the physiological effect of the noise of different intensity on man. Under noise with intensity of more than 80 dB begins difficultly to talk, level 120 dB produces the perception of pressure in eye/ear, with 140 dB the sounds give already pain, while with 160 dB occurs the mechanical damage of the organ/controls of audition. According to safety measures it cannot be worked prolonged time with the noise whose intensity exceeds 85 dB.

For a brief time are permissible the higher values of sound intensity.

During noise abatement at experimental stations, it is necessary to consider that the considerable speeds, temperatures and the volumes of exhaust gases complicate design, the selection of materials, calculation and the construction of the systems of noise suppression.

In connection with this during design and calculation of soundproofing systems of experimental stations, it is necessary to consider not only the physico-mechanical properties of sound-absorbings material, but also permissible drops of the pressure of gas flow and the available cross sections of the suction and exhaust channels of unit.

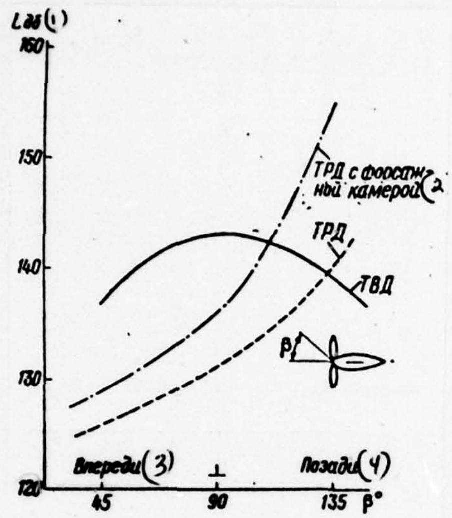

Fig. 133. Total intensity of noise depending on azimuth for engines of different types (equal thrust/rod) at a distance 9 m of noise source.

Key: (1). dB. (2). with by afterburner. (3). In front. (4). It is behind.

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In calculation is determined the quantity of secondary air, necessary for a reduction/descent in the temperature of gases.

During the organization of noise abatement, it is necessary to consider the possibility of its propagation in two ways: by air and through foundation and soil. For the prevention of noise propagation through the foundations of testing units, the latter are insulated from soil. Let us pause at the methods of noise abatement, which are spread by air.

The sound, which arose at any point of testing unit, begins to be spread in different directions and, encountering obstructions, it is reflected or partially is absorbed. Reflected one time, sound can be reflected from the opposite obstruction again and so before complete attenuation. The better material of obstruction it absorbs sound, the faster the sound energy attenuates. and vice versa, the well reflecting surfaces with their determined mutual arrangement so strengthen sound that it is continued even for a while after the cessation of the sounding of source itself. This phenomenon, called reverberation, it plays a significant role in the questions of noise abatement. In the presence of large reverberation, the intensity of auditory sensation strongly increases.

The value of reverberation depends on the degree of sound absorption by the surface of walls and noise-abating devices, also, on the volume of experimental location. From all that has been previously stated, it follows that walls, ceilings and soundproofing

devices of testing units must be made from porous materials with the good sound-absorbing ability.

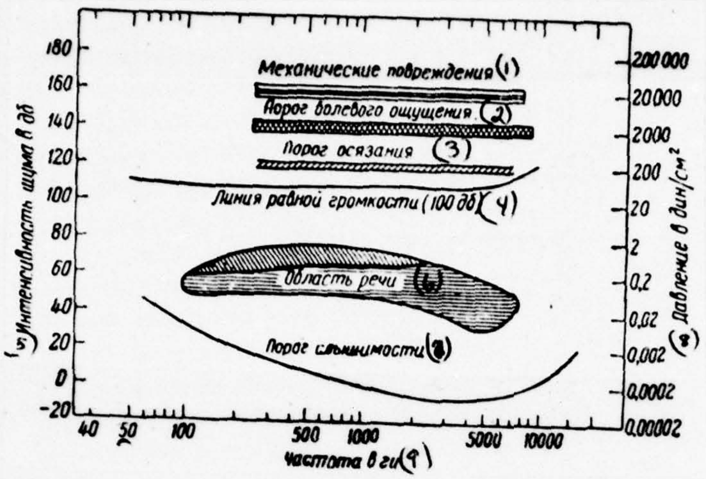

Fig. 134. Physiological effect of noise on organ/controls of audition.

Key: (1). Mechanical damages. (2). Threshold perception. (3). Threshold of tickle. (4). Line of the equal to volume (100 dB). (5). Intensity of noise in dB. (6). Region of speech. (7). Threshold of audibility. (8). Pressure in dyn/cm². (9). Frequency in Hz.

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The material, used in the systems of noise suppression and for the soundproofing of the cabin/compartments of the control of experimental stations, is must:

1) to retain life with the incidence/impingement on it of fuel/propellant, oil or water and not to lose in this case the sound-absorbing properties;

2) not to undergo erosion;

3) to be flameproof (for the silencing of exhaust);

4) solidly to be fastened to the walls of box (with its facing).

Majority of these requirements most completely satisfy fibrous materials (mineral filament, glass wool, etc.) and the porous ceramic and slag concrete blocks (solid, also, with voids).

As the cheaper materials, which successfully stun noise, but which do not satisfy a series of the stated requirements, it is possible to recommend for the systems of suction - the tree, machined by antiseptics, for exhaust systems - metal shaving or the beams of metallic wire. Fibrous materials are applied in units for a reduction/descent in the noise with wide frequency band.

The noise-abating channels can have different configuration

(Fig. 135). Ceramic porous (solid or hollow) blocks are applied for the creation of channels of the type of honeycombs cell (Fig. 136).

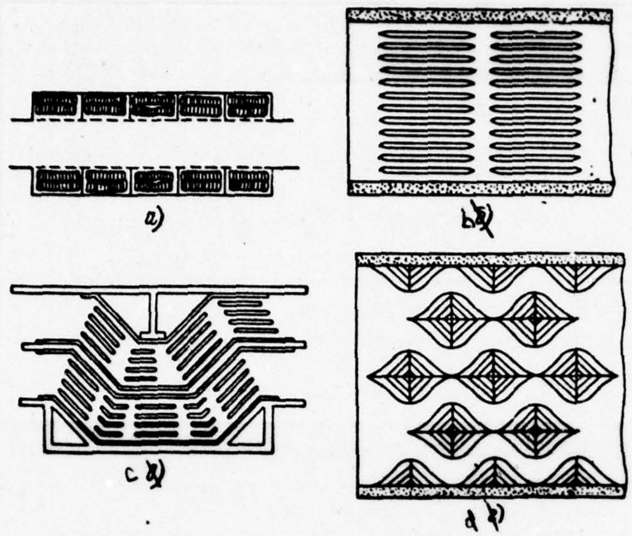

Fig. 135. Schematic of exhaust ducts with partition/baffles from panels with fibrous materials. a) channel with the panels, coated with perforated/punched steel plate, b) channel with the panels, side-by-side, c) channel with rotations, d) sinusoidal arrangement of panels.

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For the larger effectiveness of silencing blocks they misalign through the determined intervals by the half of the cross section of voids or very frequently is made channel zigzag. Ceramics less effectively decreases the noise of average and high frequencies in comparison with fibrous materials. The construction qualities of

materials for a reduction/descent in the noise determine according to their life at the different speeds of their washing gas flows, causing the erosion of material and exciting vibrations.

Many fibrous materials easily erode and are destroyed from large vibrations. In connection with this at the speeds of gas flow along surface to 25 m/s fibrous material they shield by grid or steel perforated sheets (Fig. 137a). At the speeds of flow to 50 m/s between a layer of fibrous material and the perforated/punched external laminated coating, is placed a layer of strong fabric or apply a layer of fabric with shielding wire gauze (Fig. 137b). Fabric must not be very dense, so that the high acoustic properties of the charging material were used completely.

In the speeds of gas flow 50-140 m/s, is applied additional shielding facing, inserting between the fibrous filler and the perforated/punched external facing more light/lung perforated sheets, but a 25- millimetric interval/gap between plates fills with the beams of elastic twisted steel wire. Such beams do not shrink during operation and provide the high passability/trafficability of acoustic waves (Fig. 137c).

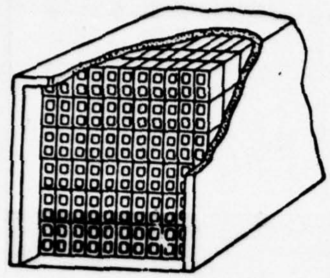

Fig. 136

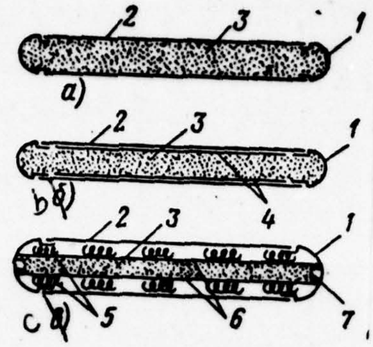

Fig 137

Fig. 136. Honeycomb channel from ceramic blocks with through voids.

Fig. 137. Constructions of noise-abating panels for different speeds of gas flow. a) to 25 m/s, b) to 50 m/s, c) 50-140 m/s. 1 - fairings, 2 - the steel perforated/punched facing, 3 - sound-absorbing material, 4 - fabric from glass fiber, 5 - the beams of metallic wire, 6 - the perforated/punched or sieve barrier, 7 - plug/silencer.

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The examined in Fig. 137 panels can be carried out in the form of vertical partition/baffles or cylindrical constructions, hung in the systems of the noise suppression of experimental stations on special grid/cascades.

The perforated/punched laminated facing of panels can be destroyed under the action of vibrations due to fatigue of metals, and also due to the loss by sheet material of plastic properties (as a result of the weakening of it by holes). In order to decrease the amplitude of the oscillations of the perforated/punched laminated facing, it must be fastened by stiffening ribs.

Fig. 138, gives decay curves of sound in decibels per the unit of the length of channel (30 cm) on frequency octaves for some panels examined above. From graphs it is evident that the most effective system of the smothering of noises for low (37-300 Hz) and average (300-1200 Hz) frequencies is the system with sinusoidal arrangement of panels. System with the thickened panels, filled by fibrous materials and the coated perforated/punched walls, provides good attenuation of noise at low frequencies. System with the zigzag arrangement of panels in channel (curved 1) provides the best attenuation of noise with high frequencies (1200-4600 Hz).

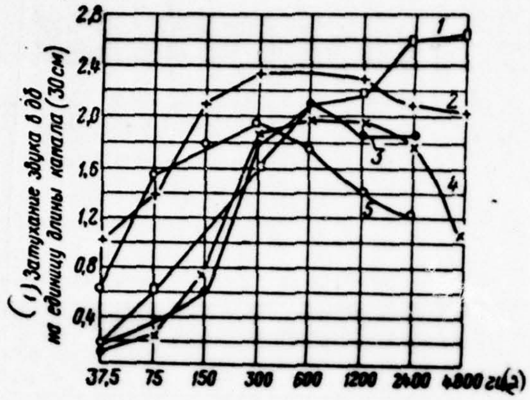

Fig. 138. Decay curve per the unit of the length of channel (30 cm) on frequency octaves for different channels. 1 - channel with panels for high speeds of flow (see Fig. 135c), 2 - channel with sinusoidal panels (Fig. 135d), 3 - laying from hollow blocks (Fig. 136), 4 - panel-partition with a thickness of 100 mm with the distance between centers 430 mm, 5 - panel-partition with a thickness of 900 mm with the distance between centers 1800 mm (Fig. 135b).

Key: (1). Sound attenuation dB per the unit of the length of channel (30 cm). (2). Hz.

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In such a way as to ensure the most effective damping of sound on entire frequency spectrum, one should apply the combined systems of

damping or system of damping, which consist of the combined panels (Fig. 139). In these panels are considered shortcomings in the panels, examined above. The system of damping, assembled from such cell/elements, provides damping sound vibrations in all range of audible frequencies and because of high effectiveness makes it possible to apply the stunring cell/elements of smallest size/dimensions.

Noise-abating element is a series of the winding channels whose walls are made from sound-absorbings material. The form of channels, along which flows the air, contributes to the damping of the sound of medium frequencies, and material of walls absorbs the high-frequency components of noise. For abatement of the ncise of low frequency, serve special cutouts - resonators.

Considerably is decreased the noise of exhaust gases during mixing to them of cold air or water. It is more rational and to considerably cheaper mix air. An even larger effect brings the system of noise suppression, based on the combination of the principles of the expansion of gases and absorption of noise. It consists in the fact that the tail cone will eject the determined quantity of air, which is located in box. Cooled thus the flow of gases enters diffuser at output/yield from which its speed it is decreased, and pressure slightly grow/rises, which makes it possible to let pass it

through the system of the slot channels, sheathed by the noise-abating materials.

Fig. 140, gives the design concept of the double sectional silencer, made from steel up to 25 mm in thickness.

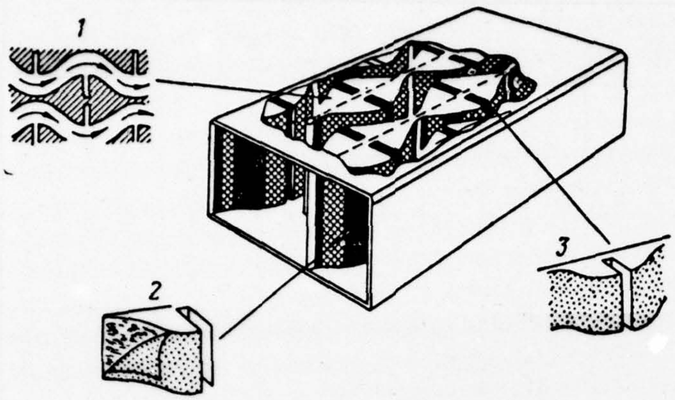

Fig. 139. Circuit of device of element of noise-abating system. 1 - the channels of the winding form, which facilitate the sound absorption of medium frequency, 2 - the materials, which absorb high-frequency sound, 3 - resonators for the damping of low frequencies.

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The protection of its housing from atmospheric effects is provided aluminum coating with a thickness of 0.1 mm, which will be applied by hot pulverization. To aluminum coating will be applied a layer of aluminum heat-resisting paint. The unit of silencer requires no special equipment. Foundation is assembled from simple concrete or brick blocks. In those places where the silencer is passed through

the wall of box, is provided for the special packing/seal whose construction makes it possible to adjust and to remove silencer without the failure of the cell/elements of building.

The optimum acoustic effectiveness of silencer under the varied conditions of testing and at different power of engine can be reached by means of the regulation of the special throttle device, available in silencer. The length of silencer approximately 30 m, weight is about 73 t.

Because of the cascade ejection of gases, is provided the protection from the "reverse/inverse jerk" of hot gases into box at the torque/moment of the cessation of the operation, which removes the need for shutter/valves or the valves between the silencer and the box.

One of the basic means of noise abatement is the soundproofing of box. Is reached this by the facing of walls, sex/floor and ceiling of box of sound-abatement panels, similar described above.

For dealing with noise transmission into the cabin/compartment of the control of unit, it is necessary to the door of the report/communication of cabin/compartment with box to make double and to cover them with sound-absorbing material. Frames and glasses of

inspection windows must be also double or even triple (not connected with each other) and, furthermore, hermetically sealed.

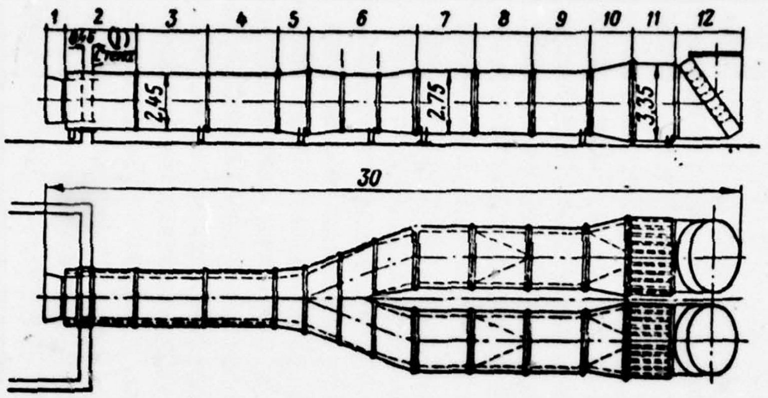

Fig. 140. Double sectional silencer. 1 - entry, 2, 3, 4 - Venturi's section, 5 - the section of diffuser, 6 - the section of bifurcation, 7 - the section of throttle, 8 - the section of the perforated/punched cone, 9 - section, 10 - the section of the perforated/punched diffuser, 11 - the section of separators, 12 - the section of cascade exhaust.

Key: (1). riding-crop.

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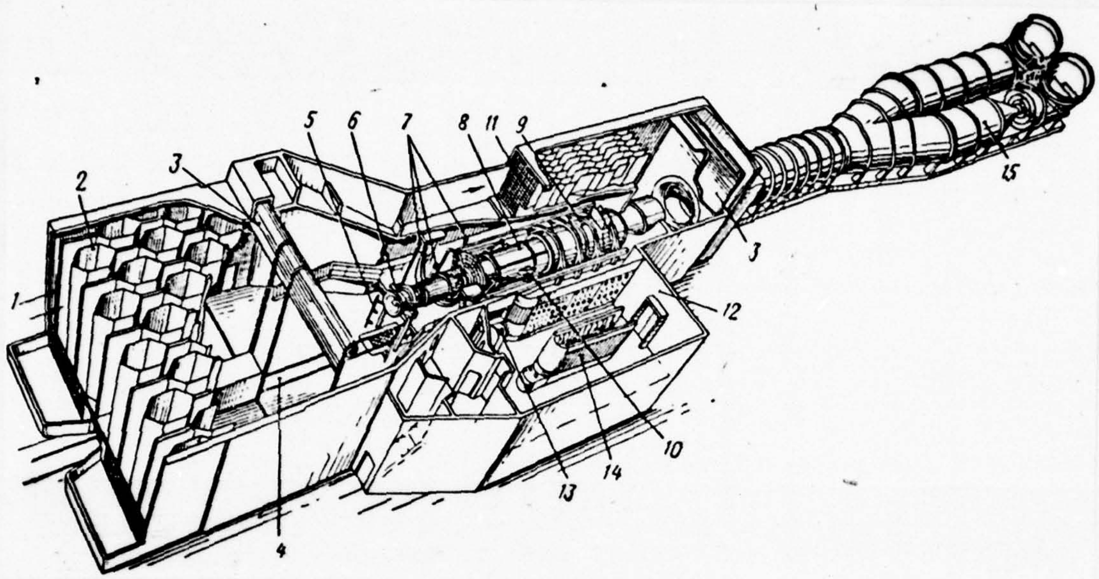

Fig. 141. Propulsion test facility with soundproofing. 1 - the primary air duct, 2 - device for silencing, 3 - louver, 4 - rails, 5 - the injector of fire extinguishers, 6 - engine, 7 - three-point engine mount, 8 - the telescopic section of exhaust duct, 9 - the removable section of exhaust duct, 10 - window in tube for observation, 11 - the second air intake, 12 - the cabin/compartment of control, 13 - inspection window and panel, 14 - manometric panel, 15 - the dual silencer.

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The trenches, which go from box into the cabin/compartment of control, and holes within the walls between them (for the packing of different main lines) must be thoroughly filled up by sound-absorbings material. The wall, which separate/liberates box from the cabin/compartment of control, must be double, with necessary air space.

Let us examine propulsion test facility with noise suppression (Fig. 141). The systems of noise suppression during suction and on exhaust are based on principles examined above.

Air is drawn in through two air intakes: through the basic 1 in the forward section of the station, in which vertically arranged/located soundproofing panels 2 form in plan/layout channels in the form of broken line, and through second air intake 11, arrange/located in the roof of experimental station, which feeds ejection pipe by air for cooling of exhaust gases. On exhaust is located dual soundproofer 15.

Examples examined above of the organization of the systems of noise suppression are related in essence to stations for testing the turbojet engines. During the layout of stations for tests of TVD, it is necessary to consider the consumption of air by screw/propellers and to increase the dimensions of the noise-abating channels.

11. Safety engineering during tests.

The technological special feature/peculiarities of the very process of testing require conducting a series of measures for the safety control and protection of the health of the service personnel.

During tests, in particular experimental, are possible breakages in the engine. In this case, the greatest danger they represent first of all breakages of rotating parts of the compressor and turbine, but in the case of testing of TVD or of bypass engine - breakage in propeller or fan.

With the emergency of the rotor of engine or propeller of part, are produced the extensive failures not only of engine itself, but also of test equipment and unit. In the practice of tests, were the cases of the explosion of the turbine disk, which was being rotated with speed approximately 450 m/s. The fragments of disk, after clearing the steel band/shroud/tire of turbine and after bending the shielding steel plate with a thickness of 20 mm, they broke the concrete wall, standing in several meters from engine, at depth 150mm

. The given example it shows, how heavy can be the consequences of such emergencies.

Inspection window of the cabin/compartment of control is recommended to make from bulletproof glass and to place outside the plane of the rotation of the rotor of engine or propellers.

During testing of jet engines, it is dangerous to be located near the airflow, entering the engine, or gas at output/yield from engine, which can be the reason for accident.

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Therefore categorically it is forbidden to enter in the box where works engine in all mode/conditions, except idling conditions. The places, subjected to the effect of the coming out from box flow, must be protect/surrounded.

For the equipment of engine on the machine tool prior to tests, for the installation of propeller (in the case of testing of TVD) around test bench creates the special area/sites, which make it possible for the service personnel to conduct the necessary works.

At propulsion test facilities important value has the fight with

the contamination of working locations by the pairs of fuel/propellant, oil and by combustion products. For this purpose, it is necessary to continuously clean air by the way of suction and exhaust ventilation.

the eliminations of the possibility of the overflow of mercury piezometric panels shield by fiberglass and establish/install from below special washer where must be assembled spilled mercury. In order to decrease the isolation/liberation of mercury vapors, it is recommended into the tubes of piezometers, filled by mercury, to fill a little kerosene or water. The permissible content of mercury vapor indoor or the surrounding atmosphere is not more than 0.01 mg by 1 m^3 of air. Since the pairs of mercury are very harmful, it is necessary to attempt not to apply in testing units instruments with mercury.

The pairs of fuel/propellants and oils are dangerous in fire sense and detrimentally they affect on the health of the service personnel. Therefore it is not possible to allow/assume any inflows in the fuel and oil systems of unit. The fuel and oil-piping layers, laid in special channels, must be connected with the system of exhaust ventilation.

The presence at the experimental station of the inflammable materials, of the free flame, heated parts of the engine and hot

exhaust gases produces the need for a strict observance of measures and rules of fire-fighting safety. Therefore at units on engine testing, besides conventional means of fire control (fire extinguishers, felt, water, sand so forth), apply special devices. Thus, for instance, in fuel system is provided for the drain line, intended for a rapid fuel dumping from an entire system into the special tanks, buried into the earth/ground. One should not apply in fuel tanks or measuring devices level gauges in the form of glass tubes.

Categorically it is forbidden indoor of experimental station to smoke, to ignite matches and to apply different inflammable instruments. It is recommended in boxes, the cabin/compartments of control and technological locations to install electric lamps in the special niches, closed with dome lights.

The most effective resources of the quenching of fire at station are foaming and carbonic acid units.

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During the emergence of fire hazard, one should include/connect fire-fighting devices. Simultaneously with this automatically must stop fuel feed and be include/connected the drain line.

Tasks in safety control advance a series of requirements for the structural constructions of station. These requirements are considered: in the planning of station; in the construction of construction structures; in the width of passes and the number of output/yields, intended to ensure if necessary the evacuation of entire personnel of station during 3 min.; for the illumination of location; for its ventilation and heating.

End section.

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Chapter VI.

TECHNOLOGY OF PRODUCTION TYPE TESTS OF JET ENGINES.

Technology of tests determines operations and transfer/transitions and regulates their order, which ensures good-quality test work and the issue of engines in accordance with technical specifications.

The technological process of engine testing can be broken into the following stages:

1) training/preparation of engine for testing (inspection, the setting of transfer branches, different kind of sensors and devices);

2) the installation of engine on the machine tool (connection of the systems of measurements, fuel and oil systems, for TVD the

setting of propellers);

3) strictly of testing;

4) the disassembly of engine from machine tool;

5) working engine after tests (taking transfer branches, sensors, devices, the damping of holes, partial lock and stopping, conservation).

Duration and the test procedure are determined by type and the construction of engine and are specified by test programs. In present chapter is examined as an example technology of the tests of turboprop engines with coaxial propellers and some special feature/peculiarities of technology of the tests of turbojet and ramjet engines.

1. Technology of production type tests TVD.

The process of production type tests of TVD in question consists of two stages.

The first stage: turboprop engine with two coaxial propellers are tested on rigid machine tool (see Fig. 117) without the measurement of effective power and reactive thrust/rod.

The second stage: turboprop engine without propellers they are tested on the combined machine tool (see Fig. 128) with the simultaneous measurement of shaft horsepower of reducer and thrust/rods of jet nozzle.

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Training/preparation for tests.

The state of equipment and instruments of testing unit has large value for the successful test work of engine, but their malfunction can lead as to the distortion of test results, so to the serious emergency of machine tool.

Machine tool and its equipment, systems and instruments at testing unit systematically are checked and subject to preventive or routine maintenance work. Preventive monthly works consist in flushing and the careful inspection of machine tool, maintenance

platforms of engine, oil and fuel systems, oil and fuel filters, fuel meters, weights, etc.

The filters of the oil and fuel systems of unit will inspect and wash in gasoline, the results of the inspection of filters will bring in into the route charts of routine maintenance work. They check, do not flow fuel, oil and other hydraulic systems. Is controlled the evenness of the course of throttle control on panel. The jamming/seizing of throttle circuit and tight course are not permissible.

Special attention when conducting of preventive works gives to the inspection of instruments, them they remove/take from panel and direct to the instrument compartment of station for testing.

Is checked the electric power supply of the automation of starting/launching by the switching on of the corresponding toggle switches and by the inspection of indicator lamps. Will inspect devices and cables for the lift of engine - electric overhead conveyors and they check their work.

Before beginning of tests, are prepared necessary documentation: technology of tests, forms of the record sheets of tests, log book and the service records of instruments.

Inspection transportation and installation of engine.

The assembled engine is received by the workers of experimental station on exchange point/item. With inspection/acceptance is produced the visual inspection of engine, is checked the presence of plug/silencers at the entry into compressor, in jet nozzle, on the branches of bench systems, and also the presence of seals on the adjusting screws of aggregate/units. Up to the torque/moment of the transfer of engine from assembly shop to experimental station, must be transmitted entire/all its technical specifications and records (log book and service records).

The brought into box engine builds up from transporting truck by electric overhead conveyor, they establish/install to the engine mount of machine tool and they fasten on it. Then connect up hoses and the turboconductors of fuel and oil systems, engine control rod.

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Are establish/installed the sensors of the measurement of

temperature, vibrations, are connected hoses and the conduit/manifolds of the measurement of pressures, etc.

In the case of testing of TVD on rigid machine tool simultaneously with connection of communications and electric wirings for the shaft of engine are installed propellers. Usually blade/vanes and propeller hubs transport separately and assemble in box.

The final operation of the setting up of propellers is testing the play of blade/vanes. For this purpose on special support/socket, they fasten indicator and its leg they will feed prior to contact with the blade/vane of front/leading screw/propeller at the determined diameter (on all screw/propellers the place of testing play noted by line).

During propeller rotation by hand, are record/written the throws of the pointer of indicator on all blade/vanes. The unit of indicator for testing of play is shown in Fig. 142. The greatest difference in the deviations must not exceed the allowed values, stipulated in operating instructions of screw/propeller (1.0-5.0 mm). Then this operation is repeated with the second screw/propeller.

The presence of large play indicates the misadjustment of blade/vanes in the beaker/sleeves of sleeve or the misadjustment of

propeller the shaft of engine, which is led to the dynamic lack of balance of propeller and engine vibration.

The presence in the box of powerful air flow during testing requires the reliable attachment of the connected to engine hoses, conduit/manifolds and electric wires.

At the termination of installation the engine is prepared for starting/launching, for which are checked the presence of the pressure of fuel/propellant in bench main line, a correctness of the control of fuel meter, a quantity of oil in oil tank. Thoroughly they check, no whether in engine, box and on the maintenance platform of foreign objects. From box remove instrument, the devices and dampers and other object/subjects.

If are carried out all preparatory works and is tested the readiness of unit, they begin directly engine starting.

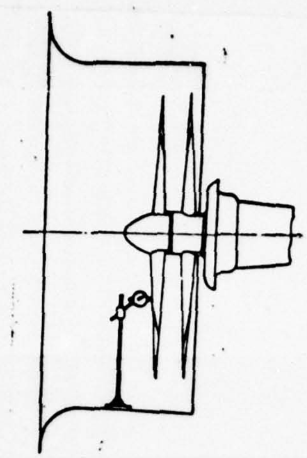

Fig. 142. Testing play of propeller blades.

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Acceptance test.

Acceptance testing begins from false start of engine with its warming up from starter without the ignition of fuel/propellant. False start are carried out for the target/purpose of the filling of the lubrication system of engine with oil, the functional checks of starter, drainage devices of the combustion chamber and removal of preservative of fuel system.

Before starting/launching it is necessary to heat oil in the lubrication system of unit to 40-50°C. It is especially necessary to preheat oil in the winter time when at the low temperatures of surrounding air the viscosity of oil is raised.

Engine starting produces with the pressure of the starting button on panel, all further operations are produced automatically up to output/yield to idling. Under the conditions of idling, the engine works during 5-10 min., after which is stopped by stop-cock. During starting/launching and in work on idling, they measure:

1) the operating time of starter;

2) the time of the activation of the motor of idling from the torque/moment of launching/starting;

3) the revolutions of the rotor of engine;

4) oil pressure;

5) the fuel consumption;

6) the temperature of gases behind turbine;

7) the temperature of oil at entrance and exit from engine.

With stop is determined the lightness/ease of the course of engine from 1000 r/min to dead lock (according to stop). This parameter shows the degree of the lightness/ease of the rotation of the rotor of engine and the absence of extraneous friction in parts and aggregate/units.

Of expedient when conducting acceptance test to combine to the breaking in of engine and the control of the basic parameters. Thus, for instance, during breakings in check work of the system of the feathering of propellers. To the breaking in of the parts of engine they carry out in several stages with gradual increase of capacity.

First stage - breaking in on revolutions with their finishing/bringing to the maximum. Propeller blades are establish/installed in this case at low pitch (floating screw/propeller). Revolutions raise gradually through 200-500 r/min; the holding time on each number of revolutions 5-10 min., during this time measure the basic parameters of engine and is checked work of aggregate/units.

Second stage - the breaking in of engine according to power with a gradual stepped increase in the latter to mode/conditions 0.7 from the nominal.

Third stage - breaking in according to power up to takeoff conditions.

Engine power rating during acceptance test is assigned by flow rate of fuel/propellant. At each step/stage of power, the engine works by 5-15 min. during which are measured all parameters.

With the engine shutdowns between stages, the breakings in produce control and the visual inspection.

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In process the breakings in check work of auxiliary units - electric generators, regulators, servodrives, hydraulic pump, air compressor, and also function of sensors and automatic devices of control system and their adjustment. By the sharp (during 1-1.5 s.) movement of sector from the detent of idling to the detent of maximum revolutions is checked the accelerating of engine and by the reverse motion of sector - the jettisoning of gas.

The results of the control of engine are checked to the end of acceptance test in all mode/conditions from idling to the takeoff. After completion of acceptance test, all regulating assemblies fasten and seal.

The fuel system of engine they preserve by the filling with light oil during warming up or false start. All works, conducted with engine during acceptance test, will bring in into record sheet.

Some defects of the poor quality assembly of engine (inflow of oil and fuel/propellant in the connections of conduit/manifolds) are removed in the process of the testing by the workers of assembly shop. Engine, passed acceptance test, dismantle from machine tool and direct to complete dismantling to assembly shop. If as a result of dismantling and inspection of parts on it is detected any digressions from technical specifications, then engine again is assembled and direct to control testing with hydraulic brake.

Monitoring tests on hydraulic brake stand.

Monitoring test of engine on machine tool with hydraulic brake consists of:

1) training/preparation of machine tool for testing;

2) the installation of engine for machine tool;

3) starting/launching and the breakings in of engine;

4) the measurement of control points;

5) the disassembly of engine from machine tool.

For the test work of engine, they assemble in assembly shop without reducer, but with technological shaft for the direct connection of the rotor of engine with hydraulic brake. In this case, is not eliminated the possibility of testing on hydraulic-brake machine tool of geared engine. For this purpose the machine tool must be equipped with slow-speed hydraulic brakes of the corresponding power. The dimensions of slow-speed hydraulic brakes are great and can overshade the entry of air into compressor. Therefore widest use received tests of TVD in ungeared version.

During training/preparation of hydraulic brake machine tool and to its tests will inspect and check the correctness of the position

of the levers of the systems of the measurement of the torsional moment and thrust/rod of jet nozzle, and also the soundness of the tap/cranes of fuel and oil systems, the lightness/ease of the course of throttle circuits and hydraulic brake, the state of lifting devices, the presence of the necessary instrument, the purity/finish and the completeness of hoses, conduit/manifolds and electric wiring.

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At the beginning of tests, must be prepared technology of tests, reference about the analysis of fuel/propellant and oils, service records and log book of monitoring-measuring equipment.

All instruments must be tested in plant laboratory within the appropriate periods, set by technology of conducting routine maintenance work.

Assembled to hydraulic-brake testing of engine, it is mounted in machine tool and are fastened in the supports of the engine mount. which they make it possible to move engine for providing the axial alignment with the rotor of hydraulic brake. The shafts of engine and hydraulic brake connect by special shaft with the splined couplings, which allow/assume the insignificant misalignment of the axle/axes of engine and brake.

Before the unit of coupling shaft, is aligned of the axle/axis of engine with the axle/axis of hydraulic brake. With the cranking of the shaft of hydraulic brake, the indicators, establish/installed to the special rod, attached on the shaft flange of brake, by their legs slip on the shaft flange of engine. In four positions through 90° in circumference, record/write the deviations the rifleman/gunner of indicators. With the aid of the movable supports of the engine mount engine they move in such a way that the deviations rifleman/gunner in radial and axial direction would be within the limits of play. The permissible play they consider: in radial direction ±0.1 mm, in axial direction ±0.05 mm. The unit of indicators for testing of centering is shown in Fig. 143.

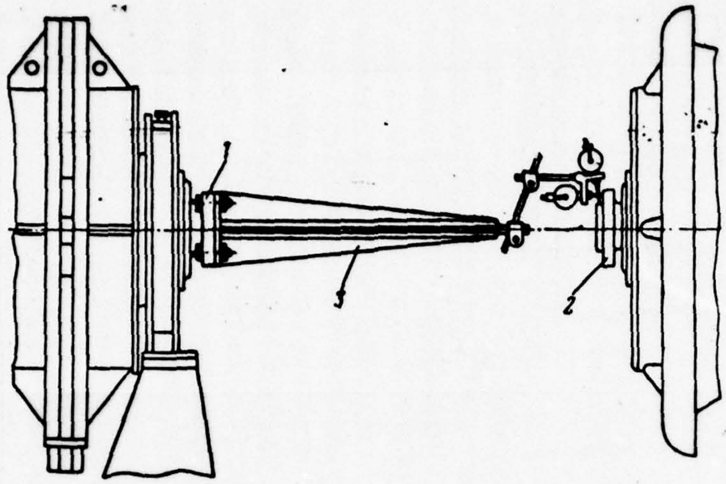

Fig. 143. Device for centering of engine with hydraulic brake. 1 - the shaft of hydraulic brake, 2 - the shaft of engine, 3 - device for a centering.

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Simultaneously with the centering of engine connect up fuel and oil systems and are installed the sensors of the measurement of pressures and temperatures.

During training/preparation of engine for starting/launching, it is necessary to verify that that there is oil in oil tank, and in the case of measurement $M_{кр}$ and R_c by hydraulic dynamometers and in the

engine from the electric drive: motor mechanic by hand, by the displacement/movement of throttle control, feeds fuel/propellant and includes ignition.

To the breaking in of engine on revolutions they produce with a stepped variation in the latter from idling to n_{max}. Operating time on each number of revolutions 5-10 min. during which are measured the parameters of engine.

At termination the breakings in produce the visual inspection of engine, its aggregate/units and hydraulic brake, are checked bench cil filters.

Before the measurement of control points, is checked the calibration of the torque meters and reactive thrust/rod. Control points are remove/taken under conditions, identical to engine power ratings during its testing with propellers. In the process of the measurement of the control points the moment of resistance, developed with hydraulic brake, changes with increase or with decrease in the water supply. The parameters usually are record/fixed at the end of work under the conditions on time. The measured parameters are processed and using the obtained materials construct characteristics. After processing of test results the fuel system of engine they preserve and engine they dismantle from machine tool.

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In assembly shop to engine, passed monitoring test with hydraulic brake, is installed reducer with the arranged/located on it aggregate/units, after which engine direct to monitoring test with propellers.

Frequently in the reducer of turboprop engine, is installed torque meter (IKM) for determining power. With sufficient accuracy/precision and operational stability of IKM monitoring test of production engine on hydraulic-brake machine tool can be not carried out or carried out selectively, for separate engines. In this case sharply is reduced the cycle of testing turboprop engine, is simplified procedure, descends the cost/value of testing. In the case of complete failure of hydraulic-brake tests, there is no need for for the equipment of experimental station by complex hydraulic-brake units.

Monitoring test with propellers.

Control testing with propellers consists in the quality control of final assembly and adjustment, conducting of the event/report of delivery to the representative of client and conservation of engine. Engine is installed on machine tool in the order, indicated above.

When conducting of monitoring test, thoroughly are checked the basic parameters of engine, and also operation of engine on all operating conditions, starting of the engine, accelerating and jettisoning of gas, work of the system of the automatic feathering of propellers, function of the aggregate/units of the systems of anti-icing.

Before each start of engine from starter is checked the lightness/ease of the rotation of rotor by the cranking of the latter in several revolutions in screw/propellers. For the characteristic of the state of the rotor of engine, is measured the stop of engine with the disconnection of fuel/propellant for n = 1000 r/min.

In the case of the deviation of the separate parameters of engine from technical specifications, it is permitted to readjust them and it is additional to test.

At the termination of the quality control of assembly and control thoroughly will inspect and wash off all filters of the fuel

and oil systems of engine. Then all devices on the aggregate/units of control system fasten and seal, after which engine they present to the event/report of delivery to the representative of client. In this case, in the test record sheet, they record/write, that the engine is fixed in accordance with technology of tests and that all its parameters correspond to technical specifications.

The event/report of delivery to the representative of client is the final detailed functional check of engine on all operating conditions with the measurement of the parameters in the presence of and at collaboration the representative of client.

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The deviations of the parameters from technical specifications and the presence of defects at the event/report of delivery are not allow/assumed.

After conducting the act of acceptance, are produced the visual inspection of engine, the inspection and the flushing of all fuel and oil filters. Are processed data, obtained during testing, are constructed the necessary curve/graphs. The engine data, obtained during monitoring test, will bring in into engine log sheet.

Passed monitoring test engine they preserve. The detailed order of internal and external preservation and packing of engine is determined by special command.

Test record sheet.

When conducting of the delivery and monitoring test of engine, is conducted the test record sheet. In the test record sheet before first engine starting, they must be recorded:

1) No engine, its aggregate/units and propeller;

2) date and the time of obtaining engine for installation;

3) No testing unit;

4) the type of testing (delivery, control at hydraulic-brake unit, control with propeller);

5) the results of the analysis of oil and fuel/propellant in the systems of unit (specific gravity/weight, viscosity, flash point, the absence of mechanical impurities and water);

6) the operation time of engine in hours and minutes for the preceding/previous tests, if they were carried out;

7) the readiness of engine for starting/launching.

In the process of tests, besides the measurements of the parameters of engine in different mode/conditions, are record/written all works, conducted with engine (elimination of defects, replacement and the control of aggregate/units). If engine stopped not on technology of testing, then are record/written in detail the reason for stop and the enumeration of subsequent works with engine. If for any reasons testing is interrupted and engine is removed from stand, then this they also record/fix in record sheet.

The test record sheets are basic document and therefore must be conducted them especially thoroughly.

Processing results.

The measured during engine testing parameters must be given to

standard atmospheric conditions. Bringing to international standard atmosph makes it possible to compare production engines friend and by friend under the condition of their tests under different atmospheric conditions (in winter and by summer, at night and in the daytime, etc.).

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During the results of tests of TVD unlike the conventional for TRD given parameters, introduce the concept of normal given parameters: $N_{e\,\text{норм}}$, $G_{\text{т. норм}}$, $C_{N\,\text{норм}}$, $R_{\text{с. норм}}$ so forth.

By normal are understood the values of the parameters of the tested engine, led to standard atmospheric conditions and obtained in one and the same positions of controls.

The normal given parameters are utilized only in the procedure of processing of results of tests of TVD. Reduction coefficients, derived on the basis of experimental tests, are given only for given construction of TVD with the determined and constant/invariable law of the control of revolutions and the fuel consumption. The values of the normal parameters are assigned by technical specifications.

Engine power ratings during taking of control points on

hydraulic-brake stand are established on load and revolutions. The consumption of fuel and other parameters of engine are defined as functions of mode/conditions. The loads, assigned to brake, calculate.

During engine tests with propellers, the mode/conditions are established according to the fuel consumption, and shaft horsepower engine and reactive thrust/rod determine by calculation on the basis of data, obtained during engine testing on hydraulic-brake machine tool. Both during the bench test with hydraulic brake and during the testing in by propellers the conformity of the data of engine to technical specifications is checked in identical engine power ratings.

Loads during the unit of mode/conditions for the bench tests of engine with hydraulic brake calculate d the order, presented below. The equivalent horsepower of gyro-prop engine is determined from formula (130). During the bench test of engine with hydraulic brake as the basis of peg count summary for the assignment of mode/conditions, is taken normal power coefficient on the shaft of engine $N_{e\,\text{норм}}$, and its value for each mode/conditions is found by the formula

$$N_{e\,\text{норм}} = mN_{э.\,\text{норм}}, \qquad (139)$$

where

$$m = 1 - \frac{0{,}91 R_{c.\,норм}}{N_{в.\,норм}}. \qquad (140)$$

Value $N_{в.норм}$ is assigned by technical specifications. The values of coefficient of m for tests under terrestrial conditions calculate according to characteristics, removed in the process of experimental tests of engine. Since tests usually pass under conditions, different from standard atmospheric conditions, the values of the load of hydraulic brake must be selected so that after the bringing to international standard atmosph the power of engine would be equal to $N_{e\,норм}$.

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Value $N_{e\,зам}$ at these atmospheric conditions for each mode/conditions is determined from the formula

$$N_{e\,зам} = K_N N_{e\,норм}, \qquad (141)$$

where K_N is the reduction coefficient, depending on pressure and temperature of surrounding air and the considering law of the control of engine in revolutions and the fuel consumption. The value of coefficient K_N - is determined according to the graphs, constructed on the basis of experimental testing of the engine of this specimen/sample.

Engine at the assigned power charges by hydraulic brake, creating appropriate braking moment on the shaft of engine. In this case, the assigned operational engine revolutions support with constants by the engine governor, which with an increase in braking moment automatically increases fuel feed.

Braking moment of hydraulic brake, equal to the torsional moment of engine, is measured in the form of force P on arm l. The value of load (force P) for assigned for the engine of mode/conditions according to the measured power is determined from the formulas

$$N_{e\,зам}=\frac{M_{кр}n}{716,2}=\frac{Pln}{716,2},$$

whence

$$P=\frac{716,2N_{e\,зам}}{ln}=\frac{716,2K_N}{l}\,\frac{N_{e\,норм}}{n}. \qquad (142)$$

Having the calibration graph/diagram of the dependence of pressure on the torque meter of hydraulic brake on load on the lever of hydraulic brake, is established the necessary engine power rating.

Calculation of normal parameters of TVD during testing with hydraulic brake.

For determining the conformity of the measured on machine tool with hydraulic brake engine data to technical specifications, it is necessary to give the values of the measured parameters at the fixed attitude of controls for normal atmospheric conditions. In the process of tests of TVD, are measured and calculate the following values: N_e, R_c, G_T, T_4^* (temperature of the stagnant flow of gases behind turbine).

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The normal values of the parameters are calculated according to the following formulas:

$$N_{e\,норм}=\frac{N_{e\,зам}}{K_N}; \quad (143)$$

$$G_{т\,норм}=\frac{G_{т.зам}}{K_G}; \quad (144)$$

$$R_{c.\,норм}=\frac{R_{c.\,зам}}{K_R}; \quad (145)$$

$$T^*_{4\,норм}=\frac{T^*_{4\,зам}}{K_T}; \quad (146)$$

$$C_{N\,норм}=\frac{G_{т.\,норм}}{N_{e.\,норм}}, \quad (147)$$

where $K_N, K_G, K_R, K_T,$ - the corresponding reduction coefficients.

The normal parameters of engine during monitoring tests with propellers calculate also according to these formulas. The engine speed both during the bench test with hydraulic brake and propellers remains constant and equal to $n_{\text{норм}}$.

In the case of deviation $n_{\text{зам}}$ from the assigned value of revolutions during calculation $N_{e\,\text{норм}}$ and $R_{\text{с. норм}}$ are introduced the corrections. Allowance finds through the graphs, constructed on the basis of experimental tests.

2. Special feature/peculiarities of endurance tests.

Endurance tests carry out by various stages. The duration of the stage of continuous operation is determined by the ultimate purpose of engine. After each stage of endurance test, will inspect engine and will fulfill some routine maintenance work.

The total quantity of stages of endurance test is determined them by duration and the established/installed resource/lifetime. The mode/conditions of testing and the operation time of engine for stage are selected so that after completion of endurance test operation time under the conditions would correspond to the declared data.

Thus, for instance, during 100-hour tests must be 40 hours of nominal, 10 hours of takeoff and 50 hours of cruise settings. The alternation of mode/conditions in stage approximately corresponds to the possible alternation of mode/conditions in operation.

Prior to endurance tests and after them are remove/taken the fundamental engine characteristics for the target/purpose of the determination of the stability of its parameters in the process of continuous operation. According to datum, on obtained during tests, is determined a change in the basic parameters of engine for the time of endurance test. The average power coefficients, reactive thrust/rod and specific fuel consumption and other parameters in the stages of endurance test calculate according to the averaged hourly consumption of fuel/propellant under the conditions. Findings summarize in table.

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During the compilation of reports about conducting of endurance test, besides the tables of the average parameters and graphs of a change of them in the process of testing, they compose the sheet/table/list of the defects, recorded in the process of testing, with the detailed description of the character of defect and its reasons. In report are placed the photographs of separate defective

parts and they give conclusion about the results of conducting of endurance test and recommendation regarding the elimination of the reveal/detect/exposed defects.

In the case of the unsatisfactory termination of testing (breakage in the parts and assemblies during tests or the considerable wear and the destruction, establish/installed with the dismantling of engine) the plant must determine the reasons for the emergence of defects, develop and take measures for their elimination. After this it is necessary to repeat testing. Even if one engine of batch did not pass testing, then they scrap entire batch. Subsequently engines can be allowed to operation, if after conducting of marked by enterprise the first selected from batch engine successfully passes series endurance test.

3. Special feature/peculiarities of tests TRD.

Turbojet engine unlike the turboprop does not have the heavily stressed reducer and propeller. Turbojet engine does not need prolonged the breaking in of parts, since the rotor of engine is rotated in antifriction bearings, but the which require careful when working gears of reducer are absent. The process of testing is

simplified even as a result of the fact that there is no need to measure the power of engine. The time, necessary for testing TRD, is considerably less than with to tests of TRD.

The thrust/rod of turbojet engine depends substantially on revolutions; therefore is required the high accuracy/precision of their measurement. During tests of TRD large value has the adjustment of temperature field behind turbine. The evaluation of field is produced in the average value of temperature and its uniformity on entirefield. Adjustment of the thrust/rod of jet engine produces with the selection of the nozzle of the necessary cross section. Decrease in the cross section of nozzle leads to an increase in the reactive thrust/rod and vice versa.

In essence the technological process of the delivery, control and endurance tests of turbojet engines is very similar to technology of the tests of turboprop engines. Preparatory works, installation, preventive works on bench equipment, processing the results of tests of TRD have much in common with the same processes with tests of TVD and therefore be examined they will not be.

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Bringing the measured parameters of TRD and international

standard atmosph carries out through by the following the formulas:

the thrust/rod of the engine

$$R_{\text{пр}} = R_{\text{зам}} \frac{760}{p_{\text{зам}}}, \tag{148}$$

engine revolutions

$$n_{\text{пр}} = n_{\text{зам}} \sqrt{\frac{288}{T_{\text{зам}}}}, \tag{149}$$

the hourly consumption of the fuel/propellant

$$G_{\text{пр}} = G_{\text{зам}} \frac{760}{p_{\text{зам}}} \sqrt{\frac{288}{T_{\text{зам}}}}, \tag{150}$$

the specific consumption of the fuel/propellant

$$C_{R\,\text{пр}} = C_{R\,\text{зам}} \sqrt{\frac{288}{T_{\text{зам}}}}, \tag{151}$$

the temperature of gases behind the turbine

$$T^*_{4\,\text{пр}} = T^*_{4\,\text{зам}} \frac{288}{T_{\text{зам}}}. \tag{152}$$

4. General information about tests PVRD.

The purpose of the tests of ramjet engines it is:

1) the quality control of the assembly of engine;

2) testing the conformity of thrust characteristics assigned;

3) the study of the stability of operating conditions of engine in different mode/conditions and the explanation of the presence of the flameouts and superheating of the separate parts of hot part;

4) testing correctness and operational stability fuel regulator;

5) testing the reliability of starting at varied conditions for M and temperature of air at the inlet.

For operational provisions for PVRD under terrestrial conditions, it is necessary to create velocity head of air at the engine inlet.

Air is fed in PVRD with the special unit, which makes it possible to change its velocity and temperature. The rate of air feed depends on the mode/conditions of engine tests. The schematic of simplest stand subsonic ramjet engine is shown in Fig. 144. Engine is installed on the machine tool, which is resting on flexible towers frame with the lever/crank device, which transmits the effort/force of thrust/rod of PVRD to force gauge.

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To avoid the distortion of velocity fields in the inlet diffuser, the axle/axis of engine must coincide with the axle/axis of air-supply branch connection. Fuel/propellant tc engine is fed from the expenditure capacitance/capacity by the bench pump, which ensures necessary according to technical specifications of flow rate and pressures. The pressure of fuel/propellant at the engine inlet is regulated from control panel of the throttle valve.

The necessary conditions of tests of PVRD is testing the reliability of starting/launching, since the engine, establish/installed on rocket or aircraft, does not possess capability for independent start and it must reliably be started in air at comparatively high flight velocities.

One of the important special feature/peculiarities of tests of PVRD is their short-life (order 2-4 min.); therefore the measurements of parameters of engine and their fixing must be produced automatically. Usually the instruments, which measure the parameters, are established on separate panel and photograph after definite intervals of time in each operating mode.

Preventive works on unit are similar those who were described above. Special attention is given to the maintenance of the complex feed system of air and to handling it.

Prior to each testing of engine, is produced the calibration of the device of the measurement of thrust/rod. The necessary conditions of preparatory works is the pressure leak test of tubes and hoses of the systems of the measurement of the parameters of air channel. The presence of insignificant air losses is led to essential distortion of results.

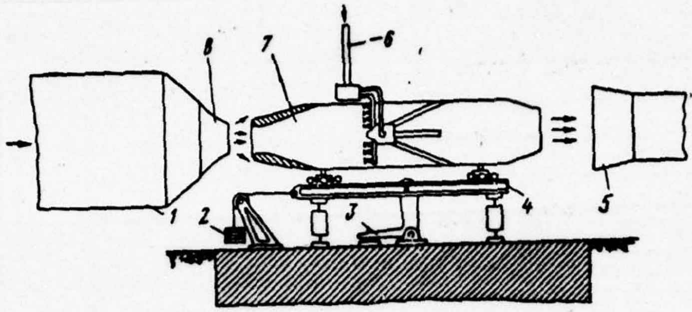

Fig. 144. Diagram of tests of PVRD. 1 - the receiver of the compressed air, 2 - calibration instrument, 3 - suction gauge, 4 - test bench; 5 - exhaust pipe, 6 - fuel input, 7 - PVRD, 8 - nozzle.

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During testing of PVRD at the unit whose schematic is shown in Fig. 144, the measured thrust/rod will be below theoretical, that not considering external resistance, to value $R_{\text{сопр}}$:

$$R = R_{\text{изм}} + R_{\text{сопр}}. \qquad (153)$$

The amount of the force of external resistance $R_{\text{сопр}}$ depends on the incident flow parameters. Is determined this force from the data of the cold blasting of engine on the basis of which is constructed the graph/diagram of the dependence $R_{\text{сопр}}$ on velocity of incident flow.

Unlike TVD and TRD, this type of engine does not require acceptance tests for rolling and breakings in; therefore in series production of PVRD, undergoes only monitoring tests. Besides monitoring tests, separate engines selectively undergo endurance tests for complete resource/lifetime.

end section.

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Chapter VII.

FLIGHT TESTS OF ENGINES.

The technical flight aircraft quality/fineness ratios to a considerable degree are determined by characteristics and the operational indices of their engines. Always there are larger or smaller differences in the actual flight characteristics of engines from the obtained at stations or under conditions high-altitude installations. Furthermore, it is necessary to determine the special feature/peculiarities of flight operations of this type of engine and its shortcomings and to mark the ways of their elimination. These positions and requirements predetermined the need of conducting the flight tests of all newly created engines and their modifications.

Each type of flight vehicle has the determined ultimate purpose and therefore the established/installed on it engines must possess

the necessary for these conditions performing characteristics. In connection with this the volume, problems and the methods of conducting the flight tests are different depending on the type of engine and designation/purpose of aircraft.

When one engine is establish/installed to different aircraft, its work is checked on each aircraft type. The need for this testing is caused by the facts that aircraft which have different designation/purpose, are utilized under dissimilar flight conditions, and also have, as a rule, the different design shaping of power plants, including of inlet ducts and gas-bleeding tubes, which exerts a substantial influence on the engine operation.

When conducting of flight tests, they impose heavy demands on the accuracy/precision of the measured parameters. Since flight experiment is very being expensive, it is desirable time of its conducting to reduce to the minimum, without harm for the quality of testing. The majority of the measured parameters is recorded by special chart recorders.

In present chapter is given only the most general information about the flight tests of engines.

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1. Aircraft for conducting the flight tests.

Flight tests of VRD are conducted either directly on the aircraft for which it is intended or on special aircraft - flying laboratories.

The primary flight tests of the newly created engine on experimental aircraft in many instances are conjugate/combined with great difficulties and risk.

The in-flight studies of engine to a considerable degree are simplified during the application/use of the special flying laboratories, created on the base of series of aircraft. Experimental engine is establish/installed in the fuselage of flying laboratory or they hang in special nacelle under wing or fuselage. Sometimes experimental engine is establish/installed above the fuselage or in the tail of aircraft. The layout of all cell/elements of power plant on flying laboratory must maximally approach a layout of the power plant of the experimental aircraft for which is intended the engine being investigated. This allows along with the flight tests of

experimental engine to produce detailed investigations and the finishing of assemblies and separate systems of the power plant of experimental aircraft.

Fig. 145, shows the general view of the flying laboratory, equipped on the base of production aircraft for testing small jet engine. Experimental engine is suspend/hung from pylon under the right wing of aircraft. Under left wing is fastened the fuel tank, which has the configuration of the power plant of experimental engine.

The schematic of the unit of ramjet engine on aircraft for subsonic flight tests is given in Fig. 146.

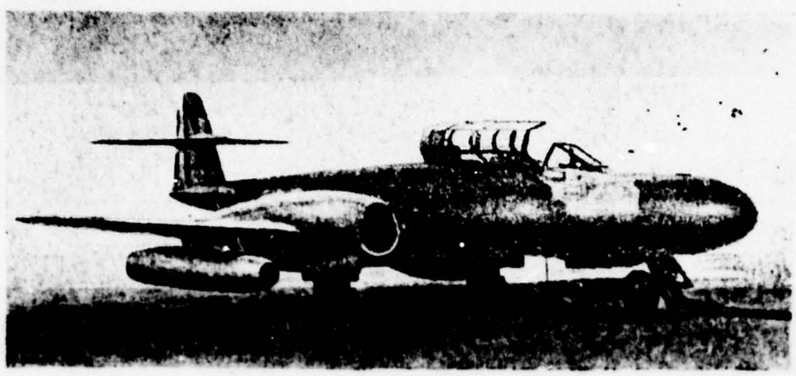

Fig. 145. Flying laboratory.

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Engine is arrange/located above the fuselage of aircraft in such a way that its axle/axis is parallel to the longitudinal axis of aircraft. When the engine being investigated is hung under fuselage, is provided for the possibility of its complete or partial retraction into the cargo hold of fuselage during taxiings, takeoffs and landings. Furthermore, in flying laboratory are establish/installed the devices, with the aid of which experimental engine can be discarded in the case of emergency. The power plant of aircraft equips with special fire prevention system.

During the conversion of production aircraft under flying laboratory from it, is remove/taken all the equipment, unnecessary during in-flight studies. This decreases the weight of aircraft and makes it possible to create the conditions, convenient for the crew activity and arrangement/permutation of research equipment.

Tests on flying laboratory make it possible to solve a whole series of questions on the in-flight study of experimental engine namely:

1) to determine the altitude-speed engine characteristics under basic conditions of its work;

2) to determine the reserve of the stability of engine under high-altitude conditions;

3) to determine temperature fields in the different cross sections of the gas circuit of engine;

4) to test the engine operation and to conduct the evaluation of its parameters on establish/installed and transient conditions;

5) to estimate control characteristics and the boundary/interfaces of the launch opportunity of engine under high-altitude and high-speed/velocity conditions;

6) to determine minimum stable operations and to test idling at different height/altitudes.

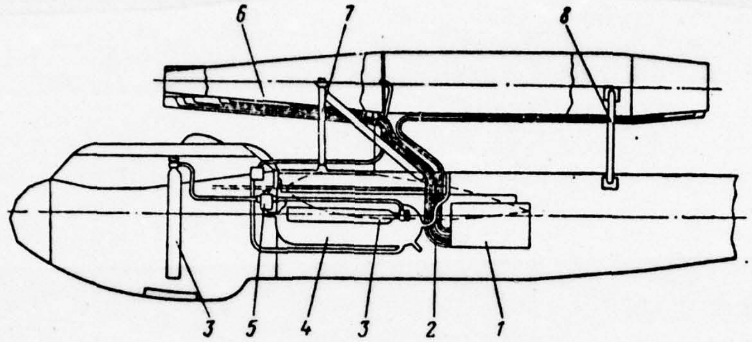

Fig. 146. Schematic of the unit of ramjet engine on aircraft. 1 - panel of measuring meters, 2 - measuring tubes, 3 - compressed-air bottles, 4 - bottle with fuel/propellant, 5 - reducer, 6 - experimental engine, 7, 8 - front/leading and rear supports.

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7) to define accelerating of engine and its work with sharp throttling/choking under varied conditions of flight;

8) to test starting/launching and operational stability of afterburner and to determine the parameters of engine at working afterburner;

9) to estimate losses of pressure and to determine the effect of the input and output devices of power plant on the engine operation;

10) to estimate work of the control systems, lubrication, engine cooling in different mode/conditions;

11) to determine vibration overloads in different engine power ratings.

Since flying laboratories are created on the base of multiengine aircraft, it is represented possible of the engine characteristic to remove/take with each mode/conditions at several given speeds and flight altitudes.

Experimental engine is created, as a rule, for new aircraft with higher flight characteristics, than in series, equipped with flying laboratory; therefore the study of new engine on flying laboratory in a number of cases proves to be limited on height/altitude, and especially on flight speed.

Furthermore, the thrust and discharge characteristics, obtained on flying laboratory, usually differ somewhat from the

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characteristics of the power plant of basic aircraft, which is explained, in the first place, the diference in the construction of input device and exhaust system.

Of that which was presented it above follows that the in-flight studies of experimental engine on flying laboratory, as thoroughly and widely they had not carried out, they cannot eliminate further flight tests and finishing on the basic aircraft for which the engine is designed.

For the tests of the individual types engines, in particular PVRD, intended for unit on guided missile, utilize the pilotless flying laboratories. Such laboratories are created on the base of the series or specially created unmanned vehicles, equipped with the necessary measuring and radio-transmitter equipment.

Flight tests in pilotless laboratories are carried out on the determined routes of the proving grounds along which are placed the stations of observation, making it possible to follow the flight of unmanned vehicle and to accept transmitted measurement data with the aid of telemetering system.

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2. Measurements when conducting of flight tests.

When conducting of the flight tests of engines, must be measured all parameters, which characterize its work. The standard schematic of the measurements of the different parameters of TRD through the gas-air duct is represented in Fig. 147. A quantity of measured parameters is determined by test program and must ensure obtaining the necessary engine characteristics. Entire/all metering equipment must be calibrated and provide the necessary accuracy/precision and the speed of measurements.

The most important parameters, which affect the operation of engine and the flight characteristics of aircraft, are barometric pressure and the temperature of air. These parameters can to a considerable degree be changed at constant altitude of flight, and because of this the characteristics of aircraft and engine for assigned altitude will be different.

In connection with the fact that altitude, i.e., vertical distance of the earth/ground, is not determined directly the characteristics of aircraft, it is accepted to determine flight altitude according to the value of barometric pressure and the data of international standard atmosph. Thus, the determination of flight

altitude is reduced to the measurement of barometric pressure.

For the simultaneous measurement of height/altitude and flight speed, is utilized ~~PST~~ PVD (air-pressure head) whose schematic together with by speed indicator and by altimeter is given in Fig. 148.

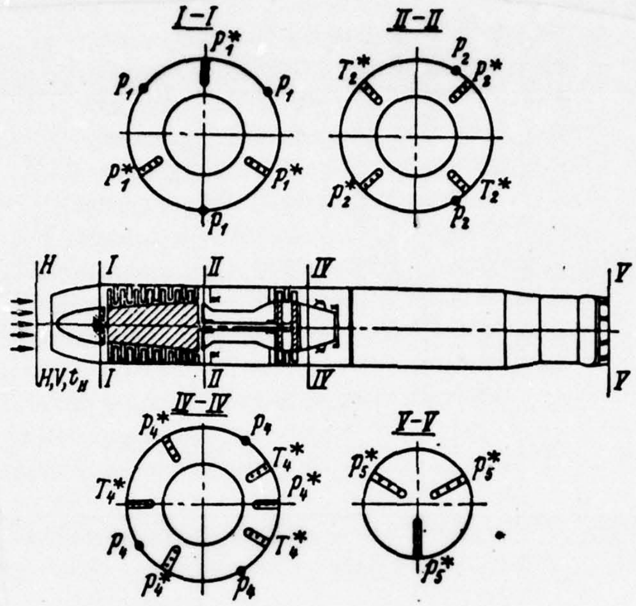

Fig. 147. Schematic of preparation of TRD. p^*_1, p^*_2, p^*_4, p^*_5, T^*_2, T^*_4 are the total pressures and the temperatures of stagnation, p_1, p_2, p_4 - static pressures.

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PVD

~~PST~~ consists of the static pressure tube 6 and of total pressure tube 5. Static-pressure tube is connected with the chamber of the static pressure of 2 speed indicators and the chamber of the static pressure of 3 altimeters. The chamber of total pressure 1 is connected with

total pressure tube 5.

Chambers 1 and 2 speed indicators are divided by diaphragm/membrane. Pressure difference in chambers 1 and 2 is led to the sagging/deflection of the diaphragm/membrane which is connected with the arrow/pointer of speed indicator or with the recording element of the chart recorder of velocity (speed recorder).

In the cavity of 4 altitude indicators, is created the vacuum and therefore the deformation of diaphragm/membrane under the action of pressure difference in cavities 4 and 3 will be proportional to static pressure. The diaphragm/membrane of altitude indicator is connected with the arrow/pointer of altimeter or with the chart recorder of height/altitude (by barograph).

For readings, are introduced the aerodynamic corrections. Tool houses of aerodynamic correction find through the calibration graphs, constructed according to the results of special calibration flight at several velocities and height/altitudes. Aerodynamic corrections to speed indicator and altimeter are unambiguously connected and therefore in flight is determined only one of these corrections, and another is calculated.

The graduation of speed indicator is produced in the value of

air density under terrestrial conditions (on international standard atmosph) and therefore that which was measured by instrument velocity taking into account instrument/tool and aerodynamic corrections is called terrestrial equivalent airspeed $c_{i\,з}$.

According to value of terrestrial equivalent airspeed, height/altitude and Mach number of flight according to special nomograms, is determined the compressibility correction $\delta c_{сж}$. Then is determined equivalent airspeed

$$c_i = c_{i\,з} + \delta c_{сж}. \tag{154}$$

For determining true flight speed, is produced the conversion for actual air density:

$$c = c_i \sqrt{\frac{\rho_0}{\rho_H}} = \frac{c_i}{\sqrt{\Delta}}; \tag{155}$$

where Δ - relative density of air ρ_H/ρ_0; ρ_0 - air density under normal conditions (with p_0 = 760 mm Hg and t_0 = +15°C); ρ_H is an actual air density at given height/altitude.

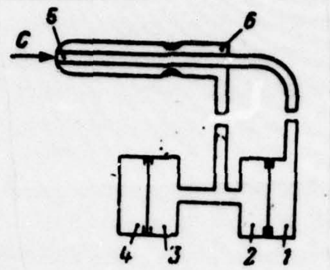

Fig. 148. Circuit of the measurement of height/altitude and flight speed. 1 - the chamber of the total pressure of speed indicator, 2 - the chamber of the static pressure of speed indicator, 3 - the chamber of the static pressure of altimeter, 4 - vacuum chamber of altimeter, 5 - total pressure tube, 6 - static pressure tube.

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Along with speed indicators in aircraft, are place deviced for the measurement directly of Mach number of flight. As is known, Mach number is determined by the relation of complete and static pressures. This dependence is used in the indicator of Mach number. In instrument the displacement of the diaphragm/membrane of complete pressure is connected with the displacement of the diaphragm/membrane of static pressure so that the rifleman/gunner of instrument shows Mach number of flight. In instrument is provided for the

thermo-metallic branching/fork, which ensures the temperature compensation for both diaphragm/membranes.

For the measurement of the temperature of surrounding air, are utilized the thermoelectric thermometers (thermocouples) and electrical resistance thermometers.

The measurement of the temperature of surrounding air on aircraft is analogous with the measurement of the temperature of flows. The temperature of surrounding air is measured by quick-setting instruments, moreover must be correctly selected the site of installation of sensor on aircraft.

The temperature of surrounding air is determined from the formula

$$T_H = T^*_{зам} - \Delta T, \tag{156}$$

where $T^*_{зам}$ is the measured temperature of stagnation; ΔT - correction to readings of thermometer for air diffusion.

Correction for braking ΔT can be determined by the formula

$$\Delta T = 0.2 r M^2. \tag{157}$$

The total pressures in the different cross sections of the gas-air duct is measured with the aid of the combs of pressure.

The measurement of number of revolutions with the aid of aircraft tachometers does not provide the necessary accuracy/precision and they are applied only for determining mode/conditions. During in-flight studies are utilized bench tachometers of the increased accuracy/precision. During the study of transient conditions, are utilized self-recorders, which make it possible to produce the continuous recording of number of revolutions.

The fuel consumption in flight can be determined with sufficient accuracy/precision with the aid of volumetric flow meter with fixation of readings by chart recorder.

Sensing element of this flow meter, schematically depicted on Fig. 149, is revolving door 1, placed into propellant stream.

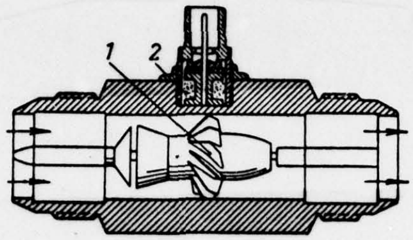

Fig. 149. Pickup circuit of flow meter. 1 - revolving door, 2 - field coil.

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The rate of the rotation of the revolving door of flow meter directly proportional to the speed of the passing through it fuel/propellant, and the total number of revolutions of revolving door in the determined time interval will characterize by itself volumetric total propellant construction.

Within revolving door is placed the permanent magnet, and above it is installed field coil. During the rotation of revolving door in field coil, is generated the electric current with frequency, proportional to rate of the rotation of revolving door. This flow

meter provides accuracy of the measurement of the fuel consumption in volumetric units ±0.5o/o. Actual volumetric flow rate is determined from the formula

$$V=\frac{n}{\tau}v\,3600+\Delta V, \qquad (158)$$

where n is a number of momentum/impulse/pulses on recorder tape for time τ s; v - the volume, which corresponds to one momentum/impulse/pulse; ΔV - the calibration correction of flow meter.

For the measurement of the fuel consumption, are applied also the flow meters, which give readings in per unit weight. For the target/purpose of the automatic introduction of correction for specific gravity of fuel to the construction of such flow meters, they connect the float densimeter, connected with potentiometer. Depending on the value of loading of float, changes the resistance of potentiometer, proportional to specific gravity of fuel.

When flight test program does not require special determining of the discharge characteristics of engine, the fuel consumption can be determined according to the value of the pressure of fuel/propellant. For this, on those who were removed previously bench characteristics is constructed the dependence of consumption on pressure before injectors. According to this dependence is determined approximate

value of the fuel consumption in flight.

The thrust/rod, which is basic index of TRD, can be determined either by direct measurement or indirectly. In the first case the thrust/rod of TRD is determined with the aid of dynamometer. For this, the engine being investigated is establish/installed in nacelle in hinged truss. The longitudinal travel of farm/truss from the forces, which effect on entire unit in flight, limit by the spring of dynamometer.

Under conditions of flight, the dynamometer records the sum of three forces - the engine thrust without taking into account of external resistance, the aerodynamic pod drag of engine and the longitudinal component of the weight of engine plant. During the study of engine in the final of count, must be determined the engine thrust without taking into account of resistance and component/term than the weight. In this case, it is conditionally accepted that aerodynamic drag with power-on will be equal to external pod drag with the shut-down engine and closed intake and outlet ducts.

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External pod drag with the shut-down engine is determined in special flight; according to the data of this flight, they calculate also the

drag coefficient of nacelle c_x. The longitudinal weight component engine plant appears as a result of the presence of angle θ between the axle/axis of engine and the line of horizon. Angle θ is measured in flight on special instrument.

The engine thrust is determined from the formula

$$R = R_{\text{зам}} + \frac{1}{2} c_x \rho S_{\text{м}} c^2 - G_{\text{д}} \sin \theta, \qquad (159)$$

where $R_{\text{зам}}$ is the measured thrust/rod; $G_{\text{д}}$ is weight of engine plant; $S_{\text{м}}$ is a cross-sectional area of the midsection of engine nacelle.

In connection with the complexity of the direct measurement of the thrust/rod of TRD in flight in a number of cases the engine thrust is determined indirectly. With sufficiently high degree of accuracy, the engine thrust can be determined by the gas-dynamic method, described in chapter V.

The air flow rate through the engine can be determined several methods. most widely used is the method of determining the air flow rate from the measurement of velocity head and static air pressure with the aid of the receivers of speed, establish/installed in the inlet duct of engine. In this case, one should consider that at the engine inlet appears certain nonuniformity of velocity fields, which

can lead to inaccuracy in the determination of the air flow rate. For obtaining sufficiently accurate results, it is necessary to establish/install in inlet duct several combs. This makes it possible to consider the character of velocity fields both by the height/altitude of channel and by circumference.

The stagnation inlet temperature into engine, necessary for determining the air flow rate, is accepted equal to the temperature of stagnation of the incident flow. This method of the measurement of the air flow rate is more convenient during the testing TRD with axial-flow compressor.

3. Procedure of the flight tests of turbojet engines.

Test programs.

During, is determined the series of question being investigated, they mark out the schematic of measurements and is selected metering equipment. By flight test program is establish/installed a quantity and duration of flight and the designation/purpose of each of them. According to each flight are determined the operating altitudes, the

speeds and engine power ratings, and also the time of the delay of aircraft and engine under the conditions before beginning of measurement.

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In program is specified the permissible accuracy/precision of the altitude hold and flight speed, engine power ratings and a quantity of repeated measurements under conditions. Depending on the target/purposes of testing and characteristic features of engines, the volume and the content of programs can be different.

During testing of experimental engine, it is necessary to determine its characteristics, to reveal performing characteristics and defects and to mark the ways of further improvement. For this, in the flight test program of experimental TRD, they include:

1) the ground tests of engine in aircraft layout for testing of its work and determination of the effect of aircraft devices on the parameters of engine;

2) control flight in the zone of airfield for the functional check of engine and aircraft (according to the results of flight is produced the necessary readjustment of engine accessories);

3) parameter determination of engine in trimmed/steady-state in all the range of operating altitudes and flight speeds; ¶ 4) testing the stability of the operation and the determination of the margin with respect to the given number of revolutions (for achievement of the maximum given revolutions testing is produced under the conditions of the climb at minimum speed of flight);

5) the functional check of engine under conditions of acceleration/dispersal and throttling/choking on different height/altitudes and flight speeds;

6) the determination of the boundary/interface of reliable starting;

7) the functional check and parameters of engine on reheat regimes, the determination of the range of the reliable starting/launching of afterburner;

8) the evaluation of the effect of aircraft inlet duct on the parameters and the stability of the operation under flight conditions;

9) the functional check of the control system of engine and accomplishing the taken law of control during change in altitude and flight speed, engine power rating and atmospheric conditions;

10) the determination of minimum stable operations at different height/altitudes;

11) the functional check of engine during the evolutions of aircraft.

When conducting of flight tests, it is desirable as far as possible to combine assignments for obtaining a maximum quantity of experimental materials in each flight.

Training/preparation for tests.

On the basis of flight test program, they select and prepare metering equipment. In aircraft is establish/installed the necessary quantity of visual and recording instruments of necessary accuracy/precision, the indicators of visual instruments derive/concluding to instrument panel in the cabin/compartment of flight engineer, and also to the special instrument panels,

establish/installed in the sections of fuselage.

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The established/installed on aircraft additional instrument panels they photograph by special cameras with remote control (Fig. 150).

Before each sortie and power plant they will thoroughly inspect and check the engine operation under terrestrial conditions. With inspection is checked: the soundness of the places of engine mount; the correctness of the installation of fuel and oil systems, electrical equipment, control; the airtightness of the connections of elements of engine gas-air channel with the input and output devices of power plant, etc. After inspection is checked the engine operation: is checked the reliability of the operation of all systems and engine accessories, establish/installed on aircraft, and also are checked starting/launching and the engine operation on basic establish/installed and transient conditions in aircraft layout. The starting/launching, the activation of the motor and work under conditions are produced in accordance with operating instructions.

The basic parameters, which characterize work of TRD during ground checks are number of revolutions, the pressure of fuel/propellant and oil, the temperature of gases behind turbine,

starting duration and acceleration time. The indicated parameters must correspond to data given in operating instructions of engine. If necessary, after engine check under terrestrial conditions, one should readjust separate assemblies.

According to the results of ground tests, is estimated work of all systems of power plant in aircraft layout, and also is determined the effect of intake and output aircraft channels on thrust/rod and fuel consumption by means of the comparison of findings with the results of plant bench tests. These tests they allow, furthermore, to estimate temperature conditions at different points of the space of power plant under the cowl and to establish/install the admissibility of work of assemblies at given temperature. During obtaining of satisfactory results, is given clearance for takeoff of aircraft.

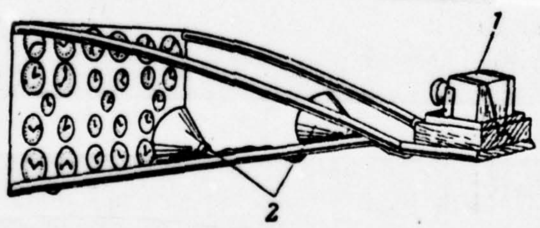

Fig. 150. Schematic of the photographing of instruments. 1 - camera, 2 - dial light.

Functional check of engine on steady-state.

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TRD are tested in trimmed/steady-state for the target/purpose of the determination of the basic parameters and operational stability of engine on height/altitude and at flight speed at different numbers of revolutions. According to the results of these tests, are constructed the altitude-speed engine characteristics.

The engine characteristics are remove/taken with a series of height/altitudes (for example, through 2000 m) from the earth/ground to the ceiling of aircraft. At each height/altitude are produced the measurements on 5-7 numbers of revolutions at 3-5 values of flight speed. During these tests measure: height/altitude and flight speed, the temperature of surrounding air, number of revolutions, the fuel consumption, the flow rate of air, the total pressure before the compressor, the pressure and temperature after compressor, pressure and the temperature of gases behind turbine, the pressure of

fuel/propellant, the temperature of oil, the position of control lever.

If in the process of tests directly was not measured the engine thrust, then it they determine in all mode/conditions by gas-dynamic method. After this are constructed the graph/diagrams of the dependence of thrust/rod, consumption of fuel/propellant, consumption of air, pressures and temperatures through channel from the engine speed for base altitudes and flight speeds.

In the course of flight tests on the study of engine in trimmed/steady-state, is checked also work of control system. Under operating conditions, must be provided the established/installed law of the control of engine, i.e., be age/held regime (physical or given) numbers of revolutions, and the assigned parameters: the consumption of fuel, the angles of the unit of adjustable compressor stators, the position of the shutter/doors of jet nozzle, etc.

Each obtained the flight test data data compare with those who were declared and if necessary are taken measures for an improvement in work of control system.

Testing the gas-dynamic stability of engine.

Unstable operation of turbojet engine is developed when working line on the characteristic of compressor intersects with separation boundary (surge).

Under flight conditions unstable operation of engine is developed in the form of the sharp knocks, which are accompanied in certain cases by the spontaneous engine shutdown. Unstable operation of TRD can occur both in those who were establish/installing and in transient conditions with a sharp increase in the number of revolutions.

On trimmed/steady-state unstable operation of engine in flight appears on the large given revolutions, i.e., under the conditions of maximum rpm at the low temperatures of surrounding air.

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These conditions most frequently are observed in flights at high altitudes at low speed. Unstable operation of engine on trimmed/steady-state can be also in work under terrestrial conditions on minimum number of revolutions and the high temperatures of

surrounding air.

On transient conditions unstable operation can be revealed during different displacement of throttle control, i.e., with a sharp increase in the fuel consumption. In this case an increase in the engine speed occurs not on operational working line, but on curved, closer to separation boundary. The character of this curve depends on the characteristics of compressor, turbine and fuel regulating equipment.

Flight tests on testing of the stability of the operation are conducted under the conditions of the climb on maximum rpm at the smallest possible flight speed. Since work under maximum conditions usually is limited on time, the climb is produced for a period of time, establish/installed for the use of this mode/conditions. Then they decrease the number of revolutions and is shifted aircraft into level flight. After engine cooling, is continued the climb under maximum conditions. In these tests are measured the height/altitude and the flight speed, the temperature of surrounding air, the number of revolutions, the compressor discharge pressure and the temperature of gases behind turbine.

Air pressure after compressor must be measured with sensitive pressure recorder on recording of which it is possible to determine

presence and character of fluctuations of air pressure. The measurement of all parameters are produced through each 500-1000 m. During the appearance of sign/criteria of surge, the pilot includes chart recorders and slowly is decreased number of revolutions.

Tests to evaluate temperature conditions in jet nozzle.

During operation of TRD, especially attentively one should control temperature of engine operating mode. The excess of the permissible temperatures of gases can lead to emergency. Therefore during the in-flight studies of new engine, must be carried out the sufficiently complete and reliable evaluation of temperature conditions and is reexamined, if it is necessary, the limiting value of the temperature of gases, establish/installed on the basis of calculation data and results of bench tests.

The parameter, which characterizes temperature conditions of TRD, is the temperature of the gases before turbine T^*_3. However, in connection with the high absolute values its and large nonuniformity of the temperature field before the turbine, to measure T^*_3 is sufficiently difficult, and therefore in the majority of cases temperature engine operating mode is estimated according to the

temperature of gases in jet nozzle.

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The temperature of gases in jet nozzle of TRD is changed with a change in the mode/conditions of work and flight conditions. To its value has effect of the characteristic of inlet ducts and gas-bleeding tubes of power plant. Since temperature field in jet nozzle is also uneven, readings of control thermocouples depend on the place of their unit. With a change in the flight conditions and engine power rating, can be changed the distribution of temperatures over cross section. All this leads to the fact that the temperature of gases in jet nozzle, measured by control thermocouples, can only approximately characterize the temperature state of engine.

Tests of TRD to evaluate the temperatures of gases in jet nozzle make it possible to test that are not exceeded the limiting values of temperature, and to determine the character of its distribution over the cross section of jet nozzle under varied conditions of flight. If necessary according to the flight test data correcting the limiting value of temperature.

For determining the character of temperature field behind turbine or in the gas-bleeding tube they establish/install several

temperature combs, connected with chart recorders. Measurements by combs make simultaneously with the measurement of temperature with control thermocouples installed in standard places.

For the correct evaluation of temperature engine operating mode, important value has accuracy/precision of the measurement of numbers of revolutions which direct-connected with the temperature of gases in jet nozzle.

Tests according to the evaluation of the temperature of gases begin with ground check of the temperature state of engine in all velocity range. Under high-altitude conditions the engine is checked on maximum rpm during the climb to the ceiling of aircraft.

If the temperature of gases exceeds at certain height/altitude the allowed value, then the engine speed descends to obtaining of the assigned temperature. The evaluation of the temperature state of engine is produced on several flights.

Tests regarding temperature field in jet nozzle are conducted in level flight on trimmed/steady-state in several height/altitudes. For obtaining stable data, the parameters of engine are measured after a 3- minute delay under the conditions.

Engine tests in transient conditions.

To ensure the normal operation of engine on transient conditions is sufficiently difficult, since the permissible from stall conditions in compressor excess of the fuel consumption upon acceleration/dispersal above the fuel consumption with trimmed/steady-state is decreased with an increase in altitude of flight. Furthermore, during an abrupt change in engine power rating is feasible under some flight conditions flameout in combustion chamber.

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Under conditions of acceleration/dispersal, are measured the height/altitude and the flight speed, the temperature of surrounding air, the number of revolutions, complete discharge pressure of compressor and turbine the temperature in jet nozzle and the pressure of fuel.

Work on the study of engine in transient conditions begins with testing of the accelerating of engine in aircraft layout under

terrestrial conditions. Accelerating is checked during the slow (in 10-20 s) and sharp (in 1-2 s) displacements of control lever from the position, which corresponds to idling, before maximum revolutions. Upon the slow giving of gas, the number of revolutions must follow the displacement of throttle control. Upon the sharp giving of gas transit time on maximum revolutions, the excess/throw/overshoot of the number of revolutions and temperature of gases in jet nozzle must not emerge the norms, establish/installed by technical specifications.

Flight tests on the functional check of engine on starting mode/conditions are conducted into all altitude range from the earth/ground to the service ceiling with a slow and fast increase in the number of revolutions. The accelerating of engine checks both on hot, i.e., after several minutes of work under maximum conditions and on the cooled engine, after work on low gas.

During testings is not allow/assumed overspeeding and temperature of gases higher than established/installed limit. With a rapid increase in the engine speed, can spontaneously stop. In this case it is necessary by stop-cock to overlap fuel feed, then to blow engine and to again renew starting/launching. The spontaneous engine shutdown can occur due to surge in compressor or flameout in combustion chamber. The reason for stop can be determined by means of

the analysis of the results of the measurement of a series of the parameters in the process of acceleration/dispersal.

A change in the basic parameters of engine in booster duration they record with the aid of chart recorders. Booster duration is counted off from the torque/moment of the beginning of the movement of control lever to the torque/moment of achieving the maximum revolutions. Upon the sharp giving of gas, the engine must emerge to the assigned mode/conditions without fluctuations of the number of revolutions.

Besides starting characteristics, by flight tests is checked the engine operation with sharp throttling/choking, i.e., during the sharp displacement of control lever from maximum rating to the position, which corresponds to idling. Testing is produced at different flight altitudes.

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With sharp throttling/choking the engine revolutions must be lowered from the maximum to the minimum for the time, not exceeding establish/installed by technical specifications. With the throttling/choking of engine must not occur the flameout in combustion chamber.

Tests to evaluate starting.

Under terrestrial conditions the acceleration of rotor is produced because of energy of starter, while under conditions of flight - because of the incident airflow. The operating mode during which the rotor of engine is rotated because of energy of the incident flow, he is called autorotation state. Number of revolutions under the conditions of autogyration depends on flight speed and determines the effectiveness of starting under flight conditions.

Before testing of starting/launching under high-altitude conditions, are produced the adjustment of ground-based starting in aircraft layout and its investigation under conditions of autogyration. For obtaining data on autorotation state at several height/altitudes at different flight speeds, is measured the engine speed with the inoperative combustion chamber. The obtained results are utilized for the preliminary adjustment of the procedure of high-altitude starting/launching.

Tests on evaluation and adjustment of starting/launching perform

in all range of height/altitudes to the service ceiling at several flight speeds in range from the minimum to the maximum speed of aircraft. Engine can be started after its cooling during approximately 10 min. In the case of unsuccessful starting/launching following starting/launching is produced not immediately, but after several minutes of flight in order to remove from engine the saved in it fuel/propellant.

During tests it is necessary to master the most effective procedure of starting/launching. For this purpose are determined optimum conditions for the time of beginning and duration of the inclusion of the pressure of fuel/propellant in the process of starting/launching, etc. Entire process of starting/launching is record/fixed by the recording equipment. During tests measure the following parameters: the number of revolutions of rotor, the pressure of fuel/propellant, air pressure after compressor, the temperature of gases behind turbine and the temperature of surrounding air.

According to test results, are determined the range of reliable starting/launching depending on height/altitude and the flight speeds. In connection with the fact that on engine starting essential effect has the temperature of surrounding air, testing according to the evaluation of the effectiveness of starting/launching they are

conducted into summer and winter time.

Study of engine in reheat regimes.

In the process of flight tests of TRD, check its work on reheat regime. This testing is produced for the study of the parameters of engine in the establish/installed reheat regime, and also at switching on and disconnection of afterburner.

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Furthermore, these tests determine the effectiveness of work of afterburner under varied conditions of flight, are reveal/detected the boundary/interfaces of reliable starting/launching and check its strength.

Considerable attention during tests is given to the investigation of the automation, work superintendent of afterburner, since the time of the beginning of the supply of booster fuel/propellant, ignition and discovery/opening the shutter/doors of jet nozzle strictly is regulated. The disturbance of the established/installed sequence of operations or their deviation with

respect to time can lead to an abrupt change in the parameters of engine, the failure of the starting/launching of afterburner and even to surge.

The engine operation on reheat regimes is checked in all altitude range and flight speeds of aircraft. According to the results of in-flight studies, determine characteristics of TRD in reheat regime, and also the data on a change in the parameters of engine and afterburner at its switching on. These materials make it possible if necessary to select the more rational law of control upon the switching on of afterburning.

The engine operation on reheat regime is considered satisfactory, if with switching on or disconnection of this mode/conditions does not occur surge, the spontaneous disconnection of the chamber and the parameters of engine remain within the limits, specified.

One Of the most serious defects, which appear in work of afterburner, is the vibration burning, capable during short time to cause large mechanical damages and even tp lead to the destruction of the chamber. Therefore in all flight conditions, afterburner must work stable, without vibration burning. During sustained combustion the switching on and the disconnection of afterburner must not cause

prolonged fluctuations of pressure through the channel of engine. But if in the chamber is observed vibration burning, then it is determined by special indicator or from the characteristic noise of afterburner. With the first sign/criteria of vibration burning the chamber they disconnect/turn off. In the process of flight tests, is determined also the boundary/interface of the reliable starting/launching of afterburner.

Investigation of inlet ducts.

Great effect on the parameters of engine and its performing characteristics have the characteristics pf inlet ducts. The selection of size/dimensions and form of inlet ducts to a considerable degree is determined by the possibilities of their layout on aircraft.

The development of the satisfactory constructions of the inlet ducts of the contemporary high-speed aircraft, which have large working range on the air flow rate, is connected with great difficulties and therefore their experimental finishing has very large value.

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The hydraulic characteristics of inlet ducts are determined preliminarily with testing of model in wind tunnel; however, in this case is not represented possible completely to estimate their effect on the engine operation under conditions of aircraft layout at different flight speeds. The presence of hydraulic losses in input devices of TRD significantly makes the fundamental characteristics of engine and its performing characteristics worse.

By in-flight studies are determined hydraulic losses in inlet ducts and their effect on the engine characteristics. For determining entry loss into compressor, are establish/installed several multipoint combs with pitot tubes, connected with chart recorders.

Hydraulic losses estimate by the value of the total pressure loss ratio

$$\sigma^*_{\text{в}} = \frac{p^*_1}{p^*_0}, \qquad (160)$$

where p^*_1 is the averaged value of the total pressure at the entry into compressor;

p^*_0 - the total pressure of surrounding air.

For determining the character of the flow about the leading edges the channel of edge, they prepare for the measurement of static pressures.

Tests are conducted on trimmed/steady-state and under conditions of acceleration/dispersal in all range of operating altitudes and velocities of aircraft. In this case, are measured all parameters, which characterize the engine operation.

Tests on aircraft make it possible to give evaluation the effect of input device on the parameters of engine by means of their comparison with data, obtained under bench conditions.

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REFERENCES

1. V. A. Baranov, M. Ye. Deuch. Experimental installation for determining the characteristics of grid/cascades by the method of the weighing reaction force. Thermal-power engineering, 1957, No 3.

2. V. A. Bodner, G. O. Fridlender, N. I. Chistyakov. Aircraft instruments, Oborongiz, 1960.

3. B. P. Bur'yanov. Magnitoelectric oscillograph, Gosenergoizdat, 1952.

4. V. S. Vedrov, M. A. Tayts. Flight tests of aircraft, Oborongiz, 1951.

5. L. Ya. Volchok. Methods of measurements in internal combustion engines, Mashgiz, 1955.

6. V. M. Dorofeyev, V. Ya. Levin. Device for the recording of the momentum/impulse/pulse of the pulsing jet (Pulse meter), transactions of KuAI, iss- 6, Kuybyshev book publishing house, 1958.

7. O. N. Yemin. Performance calculation of series of TRD with air bleed for aerodynamic investigations, coll., the "study of operating conditions in gas turbines", the transactions of MAI, iss. 82, Oborongiz, 1957.

8. Ye. Saenger. Flight tests of subsonic ramjet engine, the questions of rocket engineering, 1955, No 2.

9. V. S. Zuyev, L. S. Skubachevskiy. Combustion chambers of jet engines, Oborongiz, 1958.

10. G. P. Katys. Methods and instruments for the measurement of the parameters of nonstationary thermal processes, Mashgiz, 1959.

11. A. A. Kopstev. Pulse Meter with inductance pickup, the transactions of KuAI, iss. 6, Kuybyshevskoye book publishing house, 1958.

12. A. N. Krylov. Lectures about approximation calculus, Gostekhteorizdat, 1950.

13. M. F. Malikov. Bases of metrolcgy, Mashgiz, 1949.

14. S. F. Malikov. Introduction into technique of measurements, Mashgiz, 1952.

15. A. I. Mikhaylov. Study of flow in the combustion chambers of gas turbine engines, sb. "theory, construction, calculation and testing internal combustion engines", transactions of the laboratory of the engines of the Academy of Sciences of the USSR iss. 3, 1957.

16. R. A. Murin. Heat engineering measurements, Gosenergoizdat, 1951.

17. V. A. Nikitin. Pressure measurement and the special-purpose

instruments in Petroleum and Gas Refining, Gostoptekhizdat, 1951.

18. V. P. Preobrazhenskiy. Heat engineering measurements and instruments, Gosenergoizdat, 1953.

19. R. Penkkherst, D. Kholder. Experimental technique in wind tunnels, IL, 1955.

20. Ye. Rigards. Study of the aerodynamic noise of jet engines, the questions of rocket engineering, 1954, No 4.

21. F. Ryugg, G. Klug, S. Pey. Study of gas turbine combustors, the questions of rocket engineering, 1954, No 2, IL.

Page 217.

22. Coll. of article, "questions of testing jet engines", edited by V. M. Dorofeev and V. Ya. Levin, transactions of KuAI, iss. 8, Kuybyshev book publishing house, 1959.

23. Coll. of article "measurement of air flow", TsAGI [ЦАГИ - Central Institute of Aerohydrodynamics im. N. Ye Zhukovskiy,] iss. 19, Oborongiz, 1960.

24. Coll. of article "methods of temperature measurement", hr. I and II, edited by. V. A. Sokolov, IL, 1954.

25. V. I. Soroko-Novitskiy. Tests of tractor engines, Mashgiz, 1955.

26. B. S. Stechkin, etc. Theory of jet engines. (Rotodynamic machines), Oborongiz, 1956.

27. V. A. Tyutyunov. Tests of turbojet aircraft engines, Oborongiz, 1956.

28. A. Uorsing and J. Geffner. Methods of the treatment of experimental data, IL, 1953.

29. Khaken. Testing aviation gas turbines BMW-003A on high-altitude stand, the questions of rocket engineering, 1956, No 2.

30. "Noise suppression", TsAGI, iss. 18, Oborongiz, 1960.

31. Express-information, VINITI [ВИНИТИ - All-Union Institute of Scientific and Technical Information]. Series ATC, 1956, iss. 17, 31, 38, 42, 49; 1958, iss. 1, 11, 13, 17, 18, 23, 40, 1959, iss. 13. Series Chinese, 1957, iss. 26. Series IS, 1959, iss. 12. Series SDS,

1957, iss. 7, 13, 21, 30-31, 40, 44, 45.

32. K. P. Yakovlev. Mathematical processing of the results of measurements, the State Technical Press, 1953.

33. AFOC Provides Huge Jet Engine Test Facility, SAE Journal, 1954, VII pp.28-32.

34. Bristol Engine Division Facilities for Gas Turbine Research and Development, Flight, 1952, vol. 61, No. 2259, pp559-563.

35. Gas dynamics laboratory, Flight, 1954, X, vol. 66, No. 2387, pp 607-609.

36. Jyron test-bed, Flight, 1955, IX, No. 2435.

37. R P Probert. Simulated flight engine-test facility at SVGTE, Engineering, 1957, vol. 183, No. 4764, pp 814-823.

38. Turbine-Engine Anti-Icing Tested Atop Mt. Washington, SAE Journal, 1951, I, pp 25-28.

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